special report

Development of Field Procedures for Estimating Mass Density on Spray Deposit Cards

H. E. Cramer Company, INC ■ University of Utah Research Park ■ Contract No. 26-3843

USDA ■ Forest Service Equipment Development Center ■ Missoula, Montana

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DEVELOPMENT OF FIELD PROCEDURES FOR ESTIMATING MASS DENSITY ON SPRAY DEPOSIT CARDS

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ABSTRACT

Rapid assessment of spray deposits on sampling cards to determine the effective application rate is essential to the efficient use of aircraft in forest spray operations. The purpose of the study described in this report was to develop an objective field estimation procedure for determining the mass deposited on sample cards. The approach was to use data from previous spray trials to obtain statistical relationships of the mass median drop diameter and number of drops contained on sample cards to the mass deposited on the cards for seven spray formulations. These relationships are presented in the form of nomographs that can be used in the field for rapid assessment of the mass deposited on sample cards.

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SECTION 1
INTRODUCTION

1.1 BACKGROUND

Rapid assessment of spray deposit immediately following spray operations is essential to the effective utilization of aircraft in forest spray operations. Timely recognition that the spray deposit is unsatisfactory (for example, too spotty or of undesired density) allows the project director to take appropriate corrective actions, such as rescheduling flight operations and requesting adjustments in the flow rate or other spray parameters. While objective field procedures have been developed for estimating the volume or mass median diameter (MMD) and the drop density on spray deposit cards, current field procedures for estimating the total mass of spray deposits on cards are highly subjective and the results very according to the experience and training of the personnel making the estimates.

During the past five years, the Forest Service has conducted a series of forest spray projects in which detailed estimates of spray characteristics have been developed from the laboratory analysis of spray deposit card data obtained during these projects. The major purpose of this study was to use this relatively large body of data to develop an objective procedure for the field estimation of spray deposit mass from sample card data.

1.2 STUDY OBJECTIVES

The specific objectives of the study were to:

- Analyze the available spray deposit data from selected forest spray projects. From this analysis, determine significant statistical relationships among various spray characteristics for each type of spray, application technique and equipment

- Establish a rapid procedure for field use whereby the statistical relationships can be used to determine the mass deposited on sampling cards expressed in units of ounces per acre or gallons per acre

- Comment on the statistical probability that the relationships derived from these data can be applied to other spray materials

- Derive a set of tables (or figures) of mass median diameter versus the number of drops per square centimeter for a 1-gallon application rate

This technical report describes the approach used in achieving the study objectives and the results of the study.

1.3 ORGANIZATION OF THE REPORT

Section 2 of the report contains a description of the approach used in the statistical analysis of the sample deposit card data supplied by the Forest Service for use in the study. Detailed results of the statistical analysis are given in Section 3. The procedure developed for use in the field estimation of mass density on spray deposit cards is described in Section 4.

SECTION 2
STUDY APPROACH

In a recent study for the Forest Service (Dumbauld and Rafferty, 1977), field laboratory techniques were developed for analyzing spray deposit cards to determine the mass or volume median diameter (MMD), average mass diameter (AMD), and spray deposit densities in terms of mass deposition and drop densities as a means of characterizing the spray disseminated by small aircraft. However, the techniques developed for field laboratory use require trained personnel and perhaps several hours to analyze the sample card data and to obtain a quantitative estimate of mass deposition within an aircraft swath. As noted by Dumbauld and Rafferty, the D-max method developed by Maksymuik (1964) appears to be an effective and rapid field procedure for estimating the MMD on a spray deposit card (as well as for the entire swath) and the drop density on a card is rather easily estimated in the field. Thus, if a significant statistical relationship can be shown to exist between the MMD and AMD, then a rapid method of obtaining an objective estimate of mass deposit on a card can be defined.

2.1 THEORETICAL BACKGROUND

The approach to the development of a rapid field procedure for estimation of mass deposit on a card was based on the premise that a statistical relationship could be demonstrated between the MMD and AMD

on a sample card. This premise appears to be reasonable in view of the analytical relationships previously established between the MMD and AMD for certain types of drop-size distribution. For example, Herdan (1960, p. 82) defines the weight distribution of a log-normal drop-size distribution by the expression

$$w_i = \frac{\rho \alpha_v \sum (x_i^3 n_i)}{\ln \sigma'_g \sqrt{2\pi}} \int_{x_1/\ln \sigma_g}^{x_2/\ln \sigma_g} \exp \left[-\frac{1}{2} \left(\frac{\ln x - \ln x'_g}{\ln \sigma'_g} \right)^2 \right] d \ln x \qquad (2\text{-}1)$$

where

x_i = diameter of drop size i

w_i = weight fraction contained in drops with diameters between x_1 and x_2

n_i = number of drops of size i

ρ = drop density

α_v = volume shape factor equal to unity for spheres

σ'_g = weight geometric standard deviation

x'_g = weight geometric mean diameter

By definition, the expression for the weight geometric mean diameter is

$$\ln x'_g = \frac{\sum x_i^3 n_1 \ln x_i}{\sum x_i^3 n_i} \qquad (2\text{-}2)$$

where x'_g is, in this report, referred to the mass median diameter (MMD). The mean of the third moment of a log-normal drop distribution is defined by the expression (Herdan, 1960: p. 83)

$$\ln a_3 = \ln \left(\frac{\sum x_i^3 n_i}{\sum n_i} \right)^{1/3} = \ln x_g + 1.5 \ln^2 \sigma_g \qquad (2\text{-}3)$$

where

x_g = geometric mean diameter

σ_g = geometric standard deviation

Inspection of Equation (2-3) shows that the parameter a_3 is also the third root of the total mass M divided by the total number of drops N, such that

$$a_3 = \left(\frac{\sum x_i^3 n_i}{\sum n_i} \right)^{1/3} = \left(\frac{6M}{\pi \rho N} \right)^{1/3} \qquad (2\text{-}4)$$

For this reason, we have referred to a_3 as the average mass diameter (AMD). Herdan (1960, p. 84) also defines the relationship between x'_g and x_g as

$$\ln x_g = \ln x'_g - 3 \ln^2 \sigma_g \qquad (2\text{-}5)$$

The relationship between a_3 and x'_g can be determined by combining Equations (2-3) and (2-5) to obtain

$$\ln a_3 = \ln x'_g - 1.5 \ln^2 \sigma_g \qquad (2\text{-}6)$$

or, in our notation,

$$\ln (\text{AMD}) = \ln (\text{MMD}) - 1.5 \ln^2 \sigma_g \qquad (2\text{-}7)$$

Thus, if a statistical relationship similar to Equation (2-7) can be established by analyzing previous spray data, the total mass on a spray deposit card can be obtained from Equation (2-4), provided the total number of drops N on the card is also estimated.

The mass distribution curves developed from spray deposit card data obtained during previous spray projects are approximately log-normal. To determine the statistical relationship between the AMD and MMD from these data, we used least-squares regression techniques to evaluate the constants a and b in the expression

$$\ln (\text{AMD}) = \ln (a) + b \ln (\text{MMD}) \qquad (2\text{-}8)$$

from the spray deposit card data supplied by the Forest Service. Having determined the constants a and b, we can calculate the ratio of the mass

density on a card (expressed in units of gallons per acre) to the drop density on a card (expressed in units of drops per square centimeter) from the expression

$$\frac{M\left(\frac{\text{gallons}}{\text{acre}}\right)}{D\left(\frac{\text{drops}}{\text{cm}^2}\right)} = 5.598 \times 10^{-9}\ a^3 (\text{MMD})^{3b} \qquad (2\text{-}9)$$

where the units of MMD are micrometers. Therefore, if the MMD on a spray deposit card is estimated using the D-max method and the drop density D is determined for the card using the field-estimation techniques described by Dumbauld and Rafferty (1977), the relationship given by Equation (2-9) can be used to determine the mass density on the card.

2.2 STUDY DATA BASE

Spray deposit card data for 5 Forest Service spray projects were supplied to the H. E. Cramer Company for use in the study by FI&DM Method Applications Group (MAG), Forest Service, Davis, California. The spray formulations used in the projects and references containing detailed descriptions of the spray projects are given in Table 2-1. The total data set consisted of the spectral counts of stains in 16 size categories obtained using an image analyzer (Quantimet 720® or equivalent) from more than 12,000 Kromekote® sample cards. The spectral data for each card were punched on computer cards. The spectral drop

TABLE 2-1

SPRAY DEPOSIT CARD DATA SUPPLIED BY THE FOREST SERVICE FOR USE IN THE STUDY

Date	Project Name	Spray Formulation	Reference
1973	Pine Butterfly Test	*Bacillus thuringiensis*: 0.25 lbs. (three trials) and 0.5 lbs. (three trials) Dipel WP® per gallon, 7.346×10^{-3} lbs. Rhodamine B Extra S® per gallon, 9.375×10^{-3} lbs. Bio-Film® per gallon. *Zectran®*: 0.1 gallon FS-15 Zectran® (FS-15 contains 0.15 lbs. Zectran® per gallon) per gallon, 0.9 gallon fuel oil (three trials) and 0.8 gallon fuel oil (three trials) per gallon, 3.214×10^{-2} lbs. (three trials) and 6.643×10^{-2} lbs. (three trials) DuPont Oil Red Dye® per gallon.	Barry, *et al.*, 1975

TABLE 2-1 (Continued)

Date	Project Name	Spray Formulation	Reference
1974	Rennic Creek Trials	<u>Fuel Oil</u>: Fuel oil, 1 percent by volume Automate Red B® dye.	Eckblad, R. and J. W. Barry, 1978
1975	Region 1 Pilot Project	<u>Bacillus thuringiensis</u>: 0.5 lbs. Dipel WP® per gallon, 1.25 g/1 Rhodamine B Extra S® dye, 16 oz. Bio-Film® per 100 gallons. <u>Dylox®</u>: 1 lb. Dylox® plus Panasol AN3® to make 1 gallon. <u>Sevin 4-Oil®</u>: 0.5 gallon Sevin 4-Oil® per gallon, 0.5 gallon fuel oil per gallon, and 2 percent by volume Automate Red B® dye.	USDA Forest Service, 1978

TABLE 2-1 (Continued)

Date	Project Name	Spray Formulation	Reference
1976	Region 1 Pilot Project	<u>Dylox</u>®: 0.5 gallons Dylox® per gallon, 0.48 gallons HISOL 4-5-T® per gallon, 0.02 gallon Automate Red B® dye per gallon. <u>Orthene</u>®: 1.33 lbs. Orthene® per gallon, 0.885 gallons of water per gallon, 0.01 lb. Rhodamine B® dye per gallon.	Flavell, Tunnock and Meyer, 1977
1976	Region 9 Herbicide Spray Project	<u>2, 4-D</u>: 0.42 gallons Dow Ester 99® per gallon of water, 0.01 lb. Rhodamine B Extra S® per gallon.	D. Gorman, 1978

counts were then analyzed using a version of the ASCAS program supplied by MAG which we modified to calculate the AMD for each card. The modified ASCAS program provided estimates of the AMD, MMD, mass mean diameter, number median diameter, number mean diameter, and deposition density in mass units and drops per square centimeter for each card as well as a summary of these estimates for each of the trials in a spray project. The drop-distribution information was output to magnetic tape so that a permanent record of the spray deposit data would be available which could also be used in the least-squares regression analysis. A least-squares regression analysis computer program was then adapted for calculating the constants a and b in Equation (2-8) and other pertinent statistical parameters. The results of the least-squares regression analysis are described in Section 3.

SECTION 3

RESULTS OF THE REGRESSION ANALYSIS RELATING THE AMD AND MMD ON SAMPLE DEPOSIT CARDS

The results of the use of least-square regression techniques to evaluate the constants a and b in Equation (2-8) relating the AMD and MMD on sample deposit cards are summarized in Table 3-1. The results shown in Table 3-1 are arranged first by spray formulation, second by spray project and then according to the area in which the spray deposit cards were placed for sampling purposes. Dylox®, for example, was sprayed in both the 1975 and 1976 Region 1 Pilot Projects. Inspection of Table 2-1 shows the exact spray formulations were different for the two projects. For this reason, we ran the regression analysis program for the open areas and for all sampling cards used in each of the spray projects. It should be noted that the constants a and b calculated for the open areas and for all cards in the 1975 Region 1 Pilot Project Dylox® trials are significantly different at the 95-percent confidence level from the comparable constants a and b calculated for the 1976 Region 1 Dylox® trials. However, because we wish to obtain a general relationship for all Dylox® trials, we combined the data from the 1975 and 1976 Region 1 Pilot Projects. The combined results of the regression analysis are also shown in Table 3-1 for sample deposit cards placed at the drip-line of trees, on a sampling grid within the forest, and downwind from the spray block (drift), as well as for cards in open areas and for all sample cards.

TABLE 3-1

RESULTS OF THE REGRESSION ANALYSIS RELATING THE AMD AND MMD ON SAMPLE CARDS

Spray Formulation	Spray Project	Spray Area	a	b	Correlation Coefficient R	Standard Error of Estimate SE	Number of Cards Analyzed
Dylox®	1975 Region 1 Pilot Project	Open	0.8736	0.9543	0.886	9.458×10^{-2}	98
		All Cards	1.520	0.8537	0.952	1.263×10^{-1}	1077
	1976 Region 1 Pilot Project	Open	2.603	0.7301	0.962	7.015×10^{-2}	134
		All Cards	1.060	0.9371	0.923	1.433×10^{-1}	1002
	Combined 1975 and 1976 Region 1 Pilot Project	Open	1.396	0.8683	0.985	9.020×10^{-2}	232
		Trees	1.562	0.8530	0.951	1.328×10^{-1}	1700
		Grid	1.597	0.8318	0.928	2.314×10^{-1}	118
		Drift	2.333	0.7749	0.923	8.302×10^{-2}	29
		All Cards	1.517	0.8572	0.954	1.373×10^{-1}	2079

TABLE 3-1 (Continued)

Spray Formulation	Spray Project	Spray Area	a	b	Correlation Coefficient R	Standard Error of Estimate SE	Number of Cards Analyzed
Bacillius thurin-giensis	1973 Pine Butterfly Test	Open	1.810	0.8366	0.900	9.937×10^{-2}	591
		All Cards	2.628	0.7665	0.882	1.194×10^{-1}	2579
	1975 Region 1 Pilot Project	Open	2.167	0.7959	0.836	1.288×10^{-1}	198
		All Cards	1.602	0.8374	0.900	2.442×10^{-1}	1682
	Combined Pine Butterfly Test and 1975 Region 1 Pilot Project	Open	1.684	0.8474	0.892	1.092×10^{-1}	789
		Trees	1.669	0.8348	0.901	2.163×10^{-1}	2545
		Grid	1.008	0.9404	0.967	1.026×10^{-1}	119
		Drift	1.467	0.8733	0.948	1.414×10^{-1}	63
		Cross	2.756	0.7606	0.871	1.154×10^{-1}	745
		All Cards	1.524	0.8573	0.909	1.860×10^{-1}	4261

TABLE 3-1 (Continued)

Spray Formulation	Spray Project	Spray Area	a	b	Correlation Coefficient R	Standard Error of Estimate SE	Number of Cards Analyzed
Orthene®	1976 Region 1 Pilot Project	Open	1.692	0.8599	0.914	1.028×10^{-1}	236
		Trees	2.168	0.8056	0.927	1.076×10^{-1}	900
		All Cards	1.944	0.8280	0.929	1.084×10^{-1}	1136
Sevin 4-Oil®	1975 Region 1 Pilot Project	Open	1.286	0.8586	0.980	5.417×10^{-2}	100
		Trees	1.262	0.8701	0.935	1.451×10^{-1}	687
		Drift	1.542	0.8496	0.924	1.592×10^{-1}	71
		All Cards	1.401	0.8505	0.935	1.421×10^{-1}	858

TABLE 3-1 (Continued)

Spray Formulation	Spray Project	Spray Area	a	b	Correlation Coefficient R	Standard Error of Estimate SE	Number of Cards Analyzed
Zectran®	1973 Pine Butterfly Test	Open	1.639	0.8233	0.799	1.229×10^{-1}	235
		Trees	1.908	0.7965	0.806	1.509×10^{-1}	2314
		Drift	3.934	0.6609	0.840	1.782×10^{-1}	46
		Cross	2.256	0.7647	0.831	1.408×10^{-1}	749
		All Cards	2.023	0.7856	0.813	1.474×10^{-1}	3344
Fuel Oil	Rennic Creek Trials	Open	1.424	0.8541	0.959	1.459×10^{-1}	389
		Forest	1.215	0.8959	0.974	1.787×10^{-1}	304
		All Cards	1.319	0.8728	0.971	1.625×10^{-1}	693
2, 4-D	Region 9* Herbicide Project	All Cards	37.815	0.4318	0.780	8.233×10^{-2}	50

* Using stain factor provided by Fame Associates, Ft. Collins, Colorado.

A similar separate regression analysis was performed for sampler deposit cards for Bacillus thuringiensis (BT) spray trials conducted in the 1973 Pine Butterfly Test and 1975 Region 1 Pilot Project. Inspection of Table 2-1 shows the formulations were essentially similar, but only half the source strength of DIPEL WP® was used in three of the trials in the Pine Butterfly Test. Values of the constant a (intercept) for the open cards and all cards in the Pine Butterfly Test are significantly different from the comparable value of a for the 1975 Region 1 Pilot Project at the 95-percent confidence level. However, the values of b (slope) for the two projects are not significantly different. The results obtained by combining the sample card data from the two projects are also shown in the table. The spray area defined in the table as "cross" identifies sample deposit cards laid across the block. Some spray deposit cards in this group are in the open and some are beneath trees.

All other spray formulations were used in only one spray project and no comparison can be made between projects. The spray area identified by "forest" in the Rennic Creek Trials, where fuel oil was sprayed, is actually three sampling rows within the forest. In this case, some samplers may be beneath trees or in small openings between trees.

Inspection of Table 3-1 shows that the correlation coefficients R of the regression analyses are, in general, fairly high except for the spray formulation of herbicide 2, 4-D. For some reason unknown to us, the AMD and MMD for these trials are not highly correlated. A comparison of the regression analysis estimates of the slope and intercept for all spray areas with those obtained in the open area for each spray formulation is shown in Table 3-2. The results of the regression analysis for the open areas were used as a standard since characterization of spray aircraft is normally performed using spray deposit cards placed in open areas. As shown in Table 3-2, the value of the constant a (intercept) in the relationship between the AMD and MMD obtained for open areas is significantly different from the value calculated for all other spray areas, including the value for all cards, at the 95-percent confidence level for all spray formulations except Sevin 4-Oil® sprayed on "trees". On the other hand, the value for the constant b (slope) is only significantly different in a few cases.

We have used the values of a and b shown in Table 3-1 to construct figures showing the ratio of the mass density on a card to the drop density versus the mass median diameter on the card, using Equation (2-9) for spray deposit cards in open areas and for all cards. For example, Figure 3-1 shows the ratio of M/D as a function of the MMD on the spray deposit card for open areas sprayed with Dylox® calculated from Equation (2-9) and the parameters a and b for open areas from Table 3-1.

TABLE 3-2

COMPARISON OF THE REGRESSION RESULTS FROM VARIOUS SPRAY AREAS WITH THOSE IN OPEN AREAS

Spray Formulation	Spray Area	Significant Difference at the 95-Percent Confidence Level*	
		Intercept, a	Slope, b
Dylox®	Trees	x	
	Grid	x	x
	Drift	x	x
	All Cards	x	
Bacillus thuringiensis	Trees	x	
	Grid	x	
	Drift	x	
	Cross	x	
	All Cards	x	
Orthene®	Trees	x	
	All Cards	x	
Sevin 4-Oil®	Trees		
	Drift	x	
	All Cards	x	
Zectran®	Trees	x	
	Drift	x	
	Cross	x	
	All Cards	x	
Fuel Oil	Forest	x	x
	All Cards	x	

* x denotes significant difference at the 95-percent confidence interval when compared with the slope and intercept calculated from the regression analysis for cards in open areas.

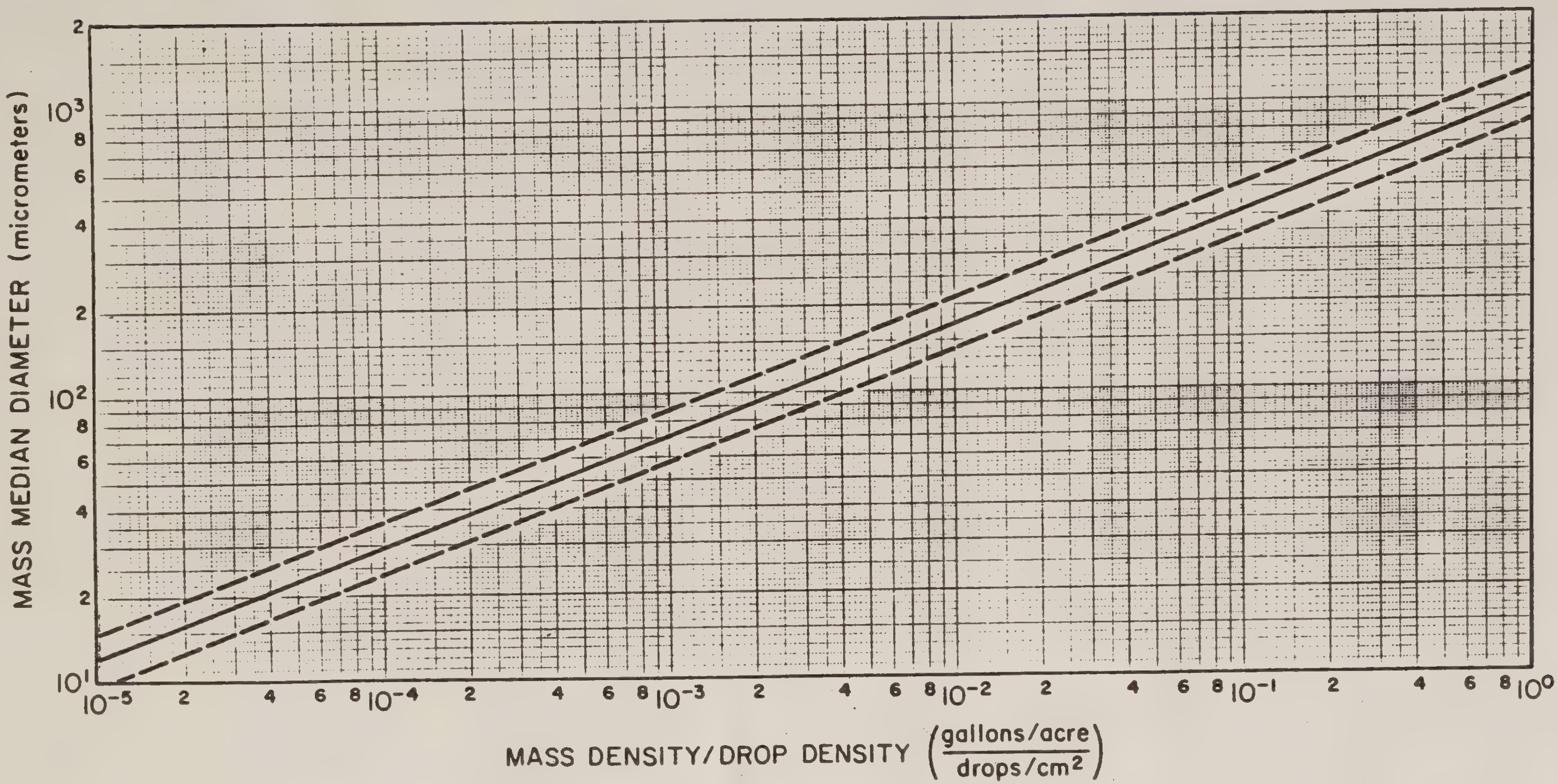

FIGURE 3-1. Ratio of mass density and drop density versus mass median diameter for Dylox® and sample cards in open areas. Dashed lines represent the 95 percent confidence interval.

The dashed lines represent the 95-percent confidence interval about the relationship expressed by Equation (2-9). The mass density on a sample card in an open area sprayed with Dylox® can be estimated from Figure 3-1 if the MMD and the drop density D on the card are known. Assuming that the MMD for a card is 400 micrometers and the drop density on the cards is 15 drops per square centimeter, the mass density on the card according to Figure 3-1 is

$$9.13 \times 10^{-2} \left(\frac{\text{gallons/acre}}{\text{drops/cm}^2}\right) \times 15 \left(\frac{\text{drops}}{\text{cm}^2}\right) = 1.37 \left(\frac{\text{gallons}}{\text{acre}}\right)$$

The confidence intervals shown in Figure 3-1 indicate that the actual mass density could be expected to vary between 0.8 and 2.3 gallons per acre 95 percent of the time for an MMD of 400 micrometers and drop density of 15 drops per square centimeter. Figures similar to Figure 3-1 for cards in open areas and all cards for the spray formulations in Table 3-1 are given in Appendix A.

SECTION 4

FIELD ESTIMATION OF MASS DENSITY ON SPRAY DEPOSIT CARDS

The method outlined below for field estimation of the mass density M on spray deposit cards requires that the drop density D and the mass median diameter MMD on the card be estimated prior to estimating the mass density. Field procedures for obtaining "quick-look" estimates of the MMD and D for a spray deposit card have been given by Dumbauld and Rafferty (1977) and are similar to the field laboratory procedures described by Maksymuik (1978) and Whyte (1978). These "quick-look" procedures for field estimation of the MMD and D on a spray deposit card are briefly outlined below for convenience. A graphical procedure for estimating the mass density on spray deposit cards developed from the results of the analysis described in Section 3 is given in Section 4.3. Finally, the results of the study are summarized in Section 4.4.

4.1 ESTIMATION OF THE MASS MEDIAN DIAMETER ON SPRAY DEPOSIT CARDS

The procedure outlined below is based on the D-max method originally suggested by Maksymuik (1964). The procedure requires that the user have a measuring magnifier with 100-micrometer divisions for estimating stain sizes. A battery-operated calculator is useful for converting stain-sizes to drop-sizes. It is assumed that the stain factor has been measured prior to the spray project. The stain factor is the

relationship between the drop size before impaction on the sampling card and the size of the stain produced by the drop on the card. A typical relationship is given by the expression

$$DD = a + b(SD) + c(SD)^2 \tag{4-1}$$

where

DD = drop diameter

SD = stain diameter

and a, b and c are constants determined in the laboratory.

The D-max method for estimating the MMD is based on inspection of the sampling card for large diameter stains. The following procedure is recommended:

(1) Make sure the stains on the card are dry.

(2) Visually inspect the card and select the largest stain appearing on the card.

(3) Measure the stain diameter to the nearest 50 micrometers using the measuring magnifier.

(4) Select the next four largest stains, measure their size, and tabulate the five largest stain diameters in descending order. If two or more stains are of the same size, they should be measured and included in the sequential tabulation of the five largest stains.

(5) Using the stain factor relationship, convert the stain diameters to drop diameters.

(6) The largest drop diameter in the tabulation is used to estimate the MMD, provided that the difference in diameter between any two successively ordered drops does not exceed 32 micrometers. If a difference greater than 32 micrometers occurs between any of the drops, the drop just below the 32-micrometer gap is used in place of the largest drop in the next step.

(7) The MMD is estimated by dividing the drop diameter selected in step (6) by the factor 2.2 if the spray aircraft speed was between 80 and 120 miles per hour during spray application, or the factor 2.5 if the speed exceeded 120 miles per hour.

4.2 ESTIMATION OF THE DROP DENSITY ON SPRAY DEPOSIT CARDS

The drop density on a spray deposit card is measured using a template of the form shown in Figure 4-1 and a large magnifying or reading glass which can be purchased in most variety stores. The template shown in the figures is for use with 17 x 11 centimeter Kromekote® cards.

(1) Place the template over the card and fasten the card and template to a clipboard. Align the top of the template (marked card edge) with the top of the Kromekote® card.

(2) Use the large magnifying glass to count the number of stains in the small (1-square centimeter) square in the upper left-hand corner. Note the number of stains on scratch paper.

(3) Continue to the next square moving down the extreme left column of squares on the template. Count the stains in the square and add to the number of stains determined for the first square (step 2). If the total number of stains exceeds 100, no more squares need be counted. If the total number of stains is 100 or less, continue to count the stains in squares until the total number of stains exceeds 100 or until the stains in all squares are counted.

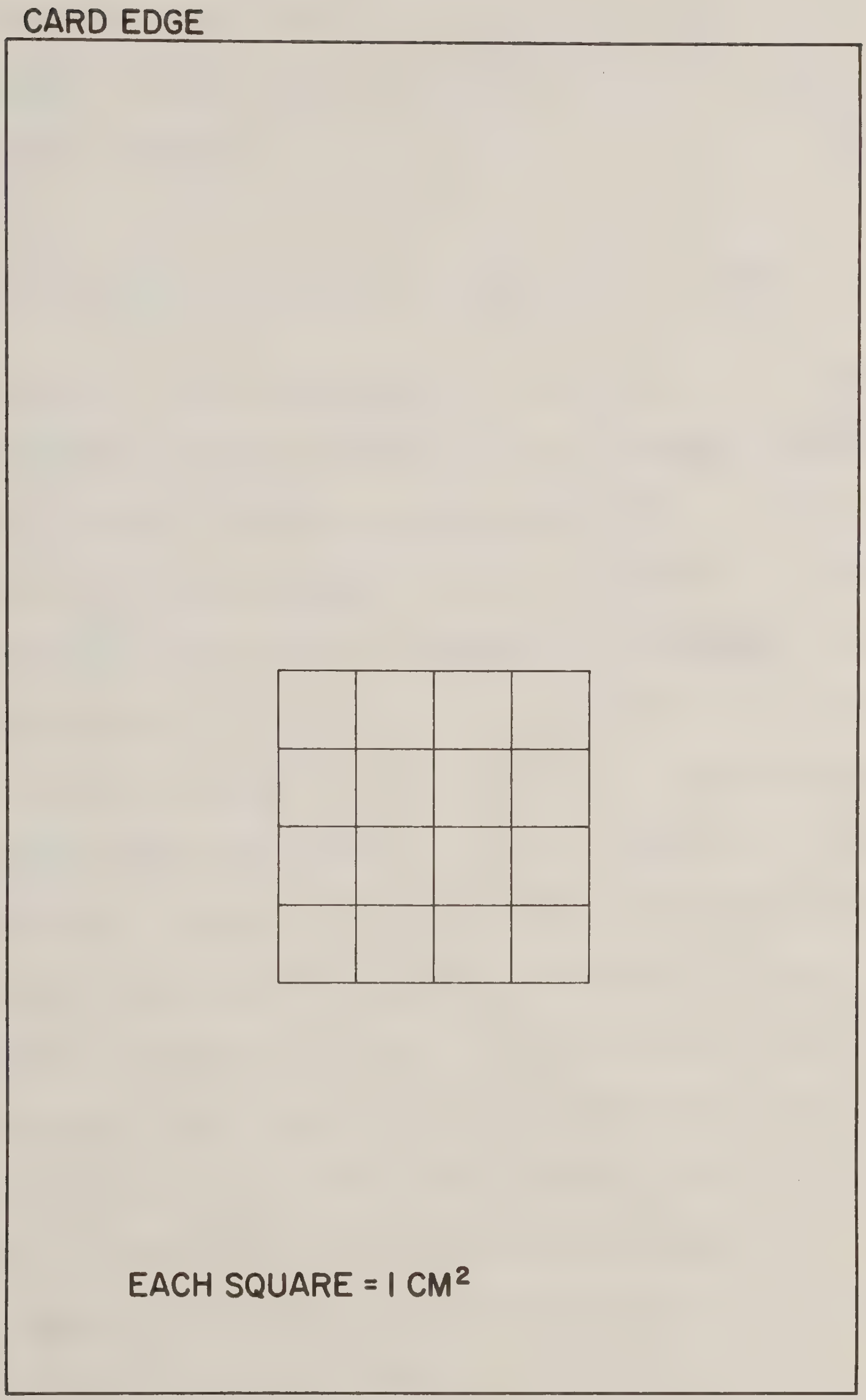

FIGURE 4-1. Template for counting of drops on sampler cards in the field. Reproduce this card on clear film or tracing paper for actual use.

(4) Divide the total number of stains by the number of squares counted to obtain the drop density D in units of drops per square centimeter.

4.3 ESTIMATION OF THE MASS DENSITY ON SPRAY DEPOSIT CARDS

Nomographs have been constructed for field use in the determination of the mass density in units of gallons per acre based on Equation (2-5) and the results of the regression analysis described in Section 3. For example, Figure 4-2 is a nomograph for use in estimating the mass density of Dylox® sprayed by an aircraft on spray deposit cards placed in open areas. The estimate of mass density is obtained from the nomograph by using a straight-edge to draw a line connecting the drop density estimate (left-hand scale) for the card obtained by using the procedure described in Section 4.2 above. The mass median diameter estimate (right-hand scale) for the card is obtained by using the procedure described in Section 4.1 above. The mass density in units of gallons per acre is then read at the point where the straight line intersects the center scale. The example straight line in Figure 4-2 drawn between an MMD of 400 micrometers and drop density of 15 drops per square centimeter indicates a mass density of about 1.4 gallons per acre of Dylox® on the spray deposit card.

Nomographs for estimating the mass density on spray deposit cards in open areas and all areas for the spray formulations involved in this

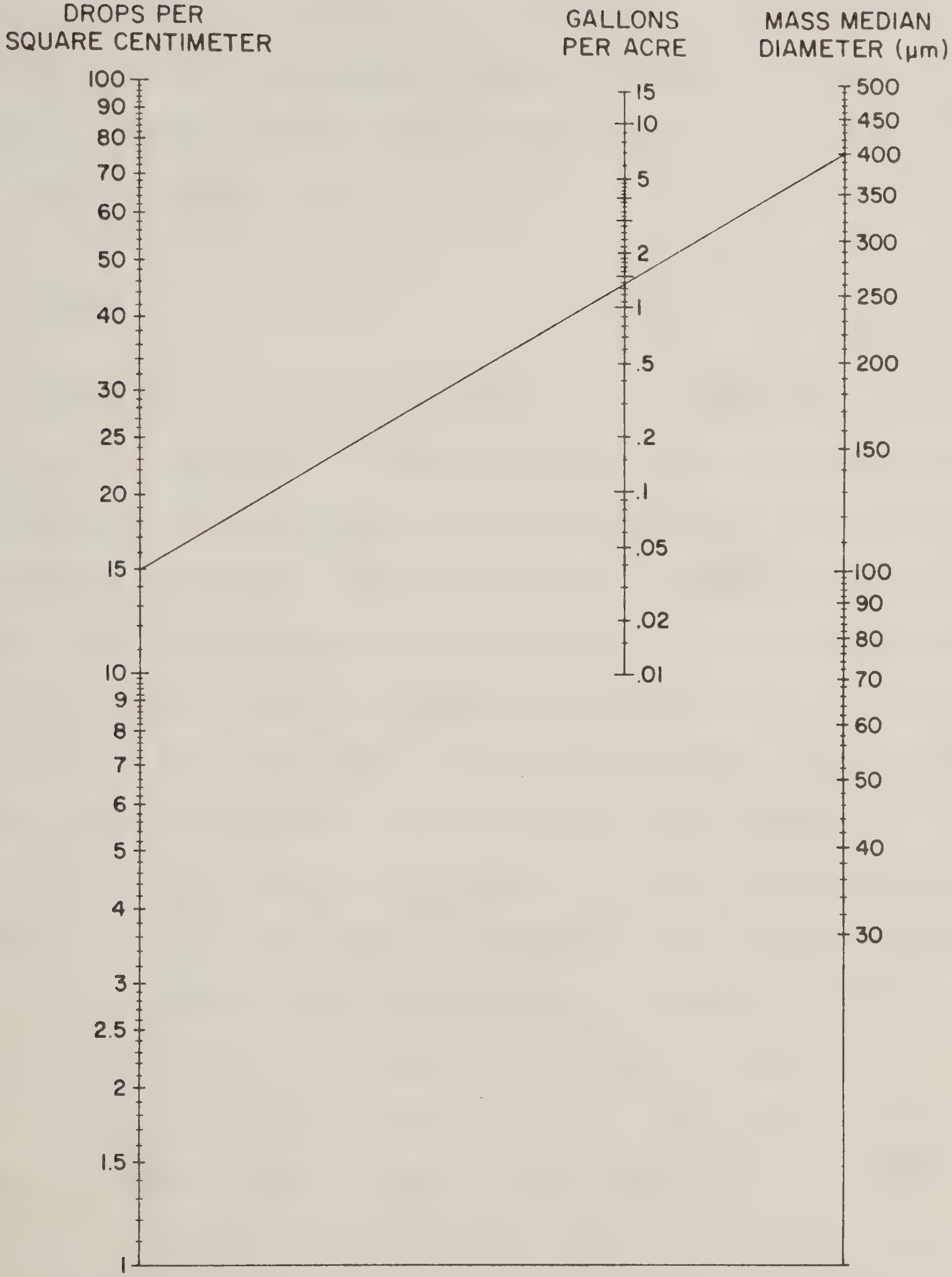

FIGURE 4-2. Nomograph for field estimation of mass density (gallons/acre) of Dylox® from the mass median diameter and drop density (drops/square centimeter) on sample cards in the open.

study, except for the herbicide 2, 4-D, are given in Appendix B. It should be noted that the nomographs can also be used to define the relationship between the mass median diameter and drop density for a given spray application rate.

4.4 SUMMARY

A graphical procedure for obtaining "quick-look" estimates of the mass density on Kromekote® spray deposit cards has been developed from a least-squares regression analyses of spray characteristics measured on spray deposit cards from 5 Forest Service spray projects. In the regression analysis, relationships were established between the average mass diameter and mass median diameter on spray cards placed in open areas, beneath tree drip-lines, on sampling grids within the forest and in open areas, and downwind from spray blocks. Relationships were developed for 7 spray formulations, including Dylox®, *Bacillus thuringiensis*, Orthene®, Sevin 4-Oil®, Zectran®, fuel oil and the herbicide 2, 4-D. Relatively high correlations were obtained for the relationships between the mass median and average mass diameters for all spray formulations except the herbicide 2, 4-D. The results of the regression analysis indicate there are significant differences in the relationships developed for cards used to sample in open areas as compared to the relationships determined for cards used to sample spray deposits beneath the drip-lines of trees and other areas, even for the same spray formulation. There are also significant differences at the

95-percent confidence level between the results obtained using different formulations of the same active ingredient (Dylox®, for example). For this reason, it appears that relationships between the average mass and mass median diameters derived for a given spray formulation cannot be applied to other spray materials with a high degree of confidence, pending additional research.

The results of the regression analysis were used to construct nomographs for estimating the mass density in units of gallons per acre on sample cards from a knowledge of the estimates of the drop density and mass median diameter on the spray deposit card. The nomographs are intended for use in performing a preliminary assessment of the mass density on sample cards and are not meant as a substitute for the more accurate field laboratory assessment of mass deposition. The confidence interval bands for the statistical relationships established between the average mass and mass median diameters on a spray deposit card (see Appendix A) show that the mass density estimates obtained using the nomographs are only approximate and should be verified by laboratory assessment.

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APPENDIX A

This appendix contains figures showing the ratio of mass density and drop density versus mass median diameter for sample cards in the open and all cards and for the various spray formulations applied in the spray projects studied. The dashed lines in the figures represent the 95 percent confidence interval about the line of regression shown by the solid line.

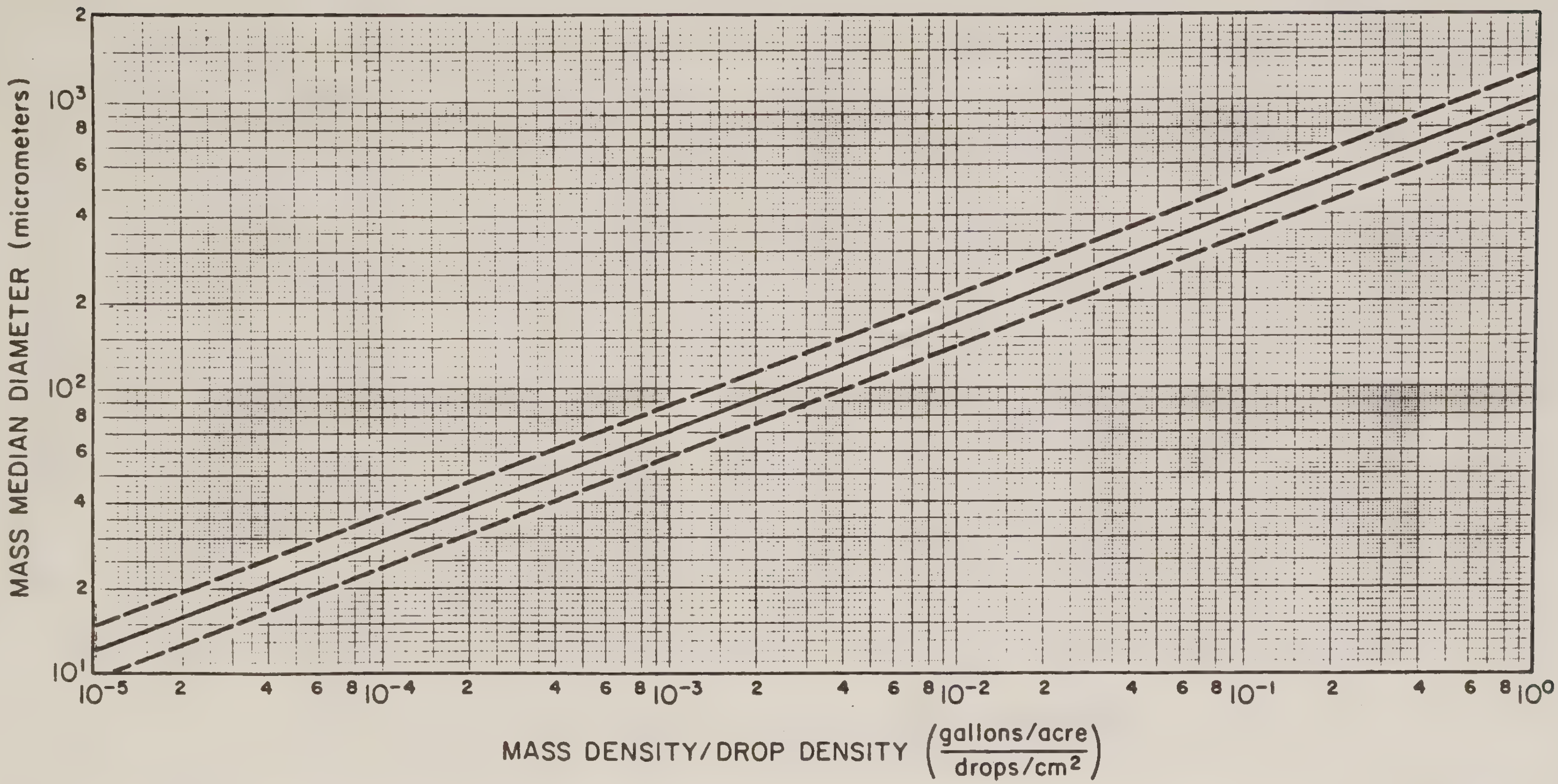


FIGURE A-1. Ratio of mass density and drop density versus mass median diameter for Dylox® and sample cards in open areas. Dashed lines represent the 95 percent confidence interval.

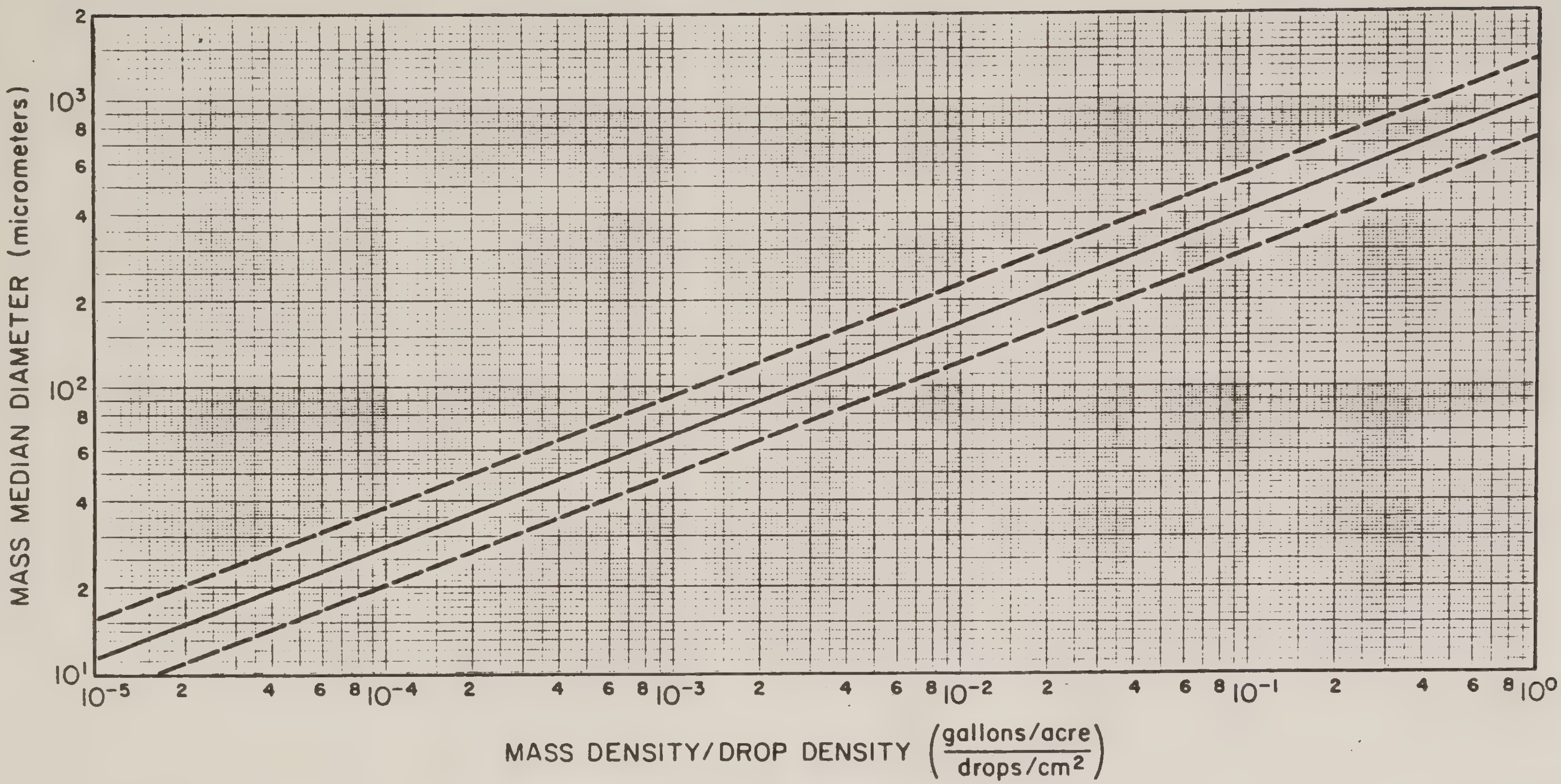


FIGURE A-2. Ratio of mass density and drop density versus mass median diameter for Dylox® and all sample cards. Dashed lines represent the 95 percent confidence interval.

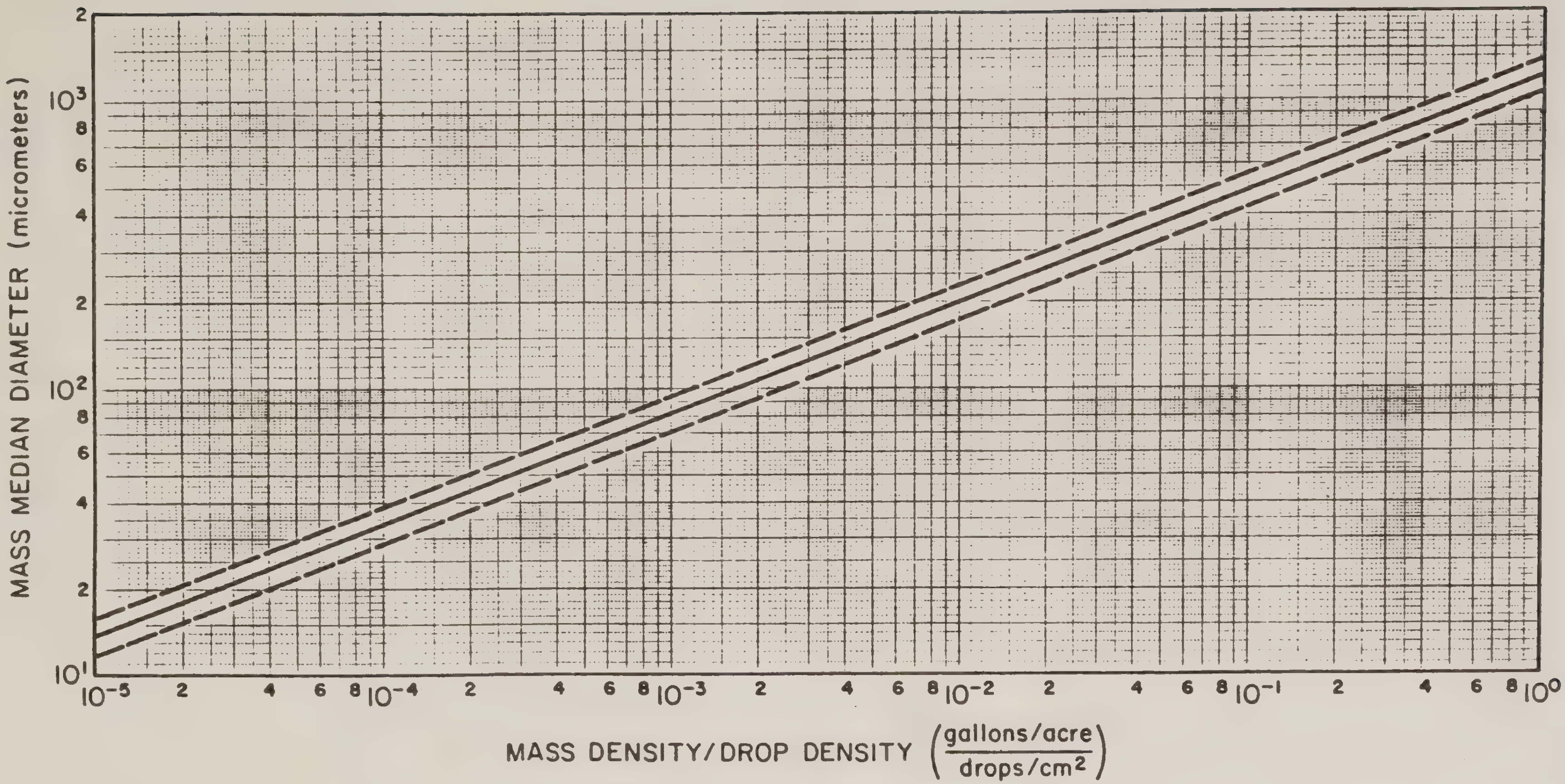


FIGURE A-3. Ratio of mass density and drop density versus mass median diameter for Sevin 4-Oil® and sample cards in open areas. Dashed lines represent the 95 percent confidence interval.

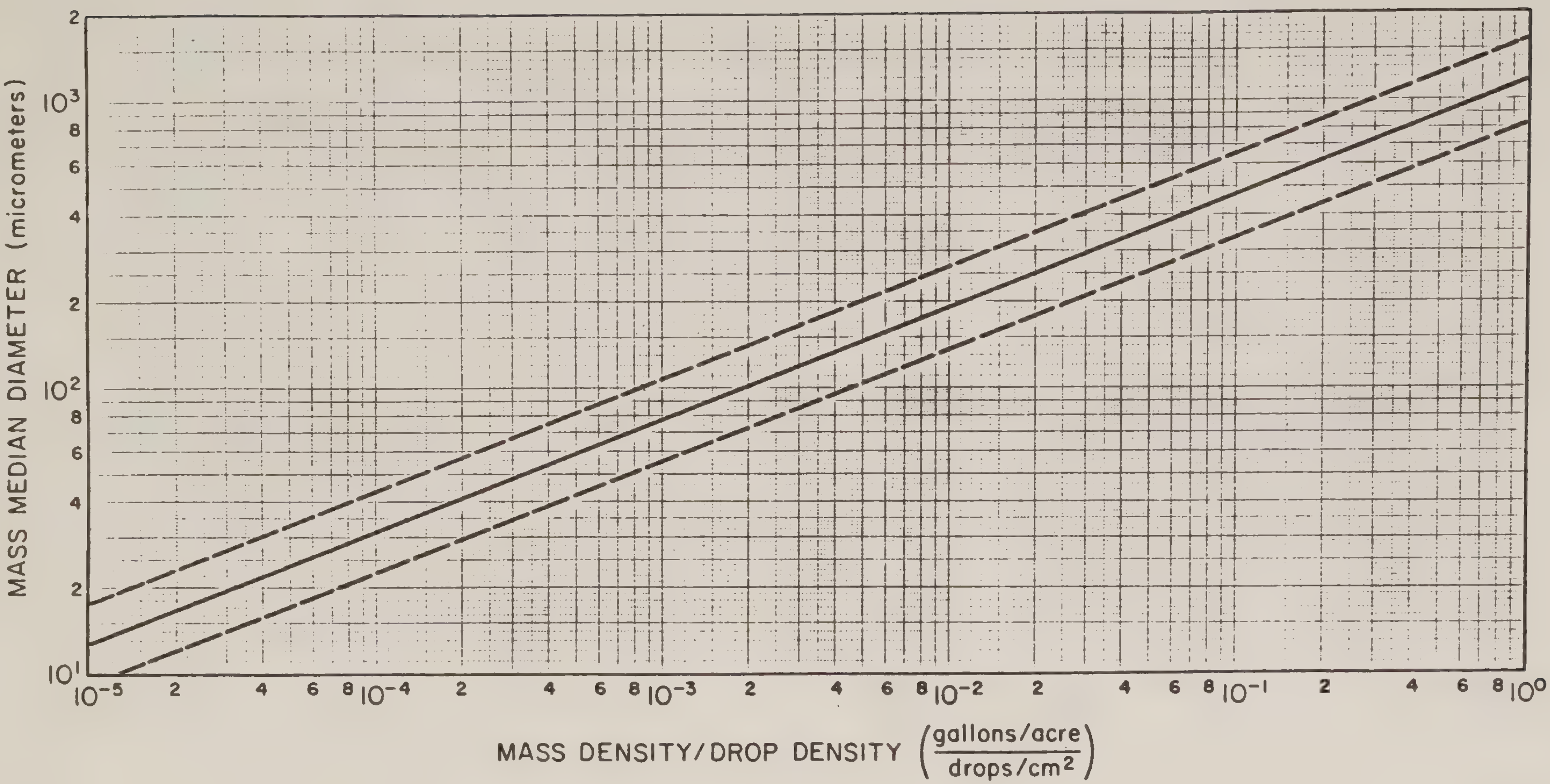


FIGURE A-4. Ratio of mass density and drop density versus mass median diameter for Sevin 4-Oil® and all sample cards. Dashed lines represent the 95 percent confidence interval.

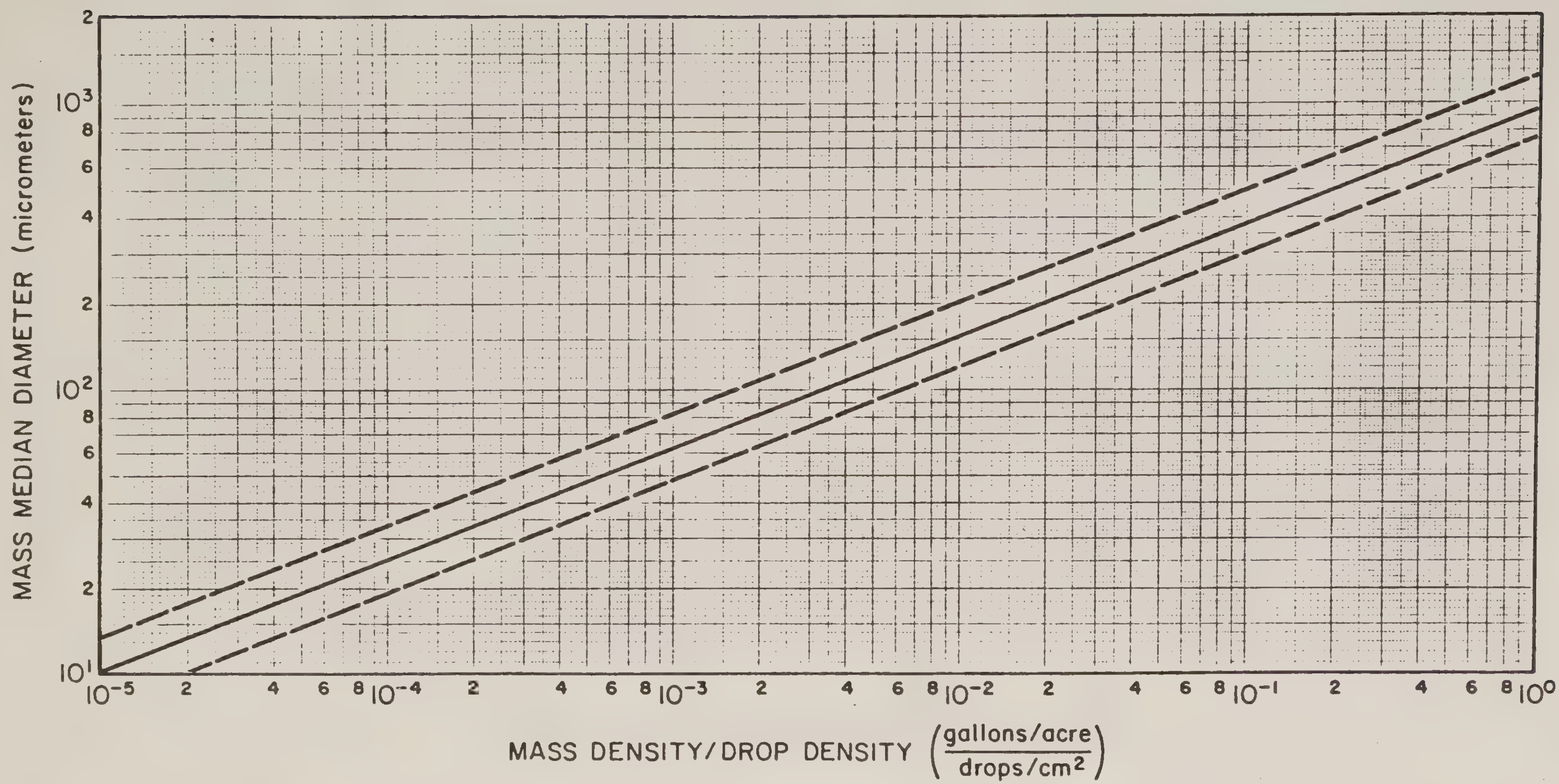


FIGURE A-5. Ratio of mass density and drop density versus mass median diameter for *Bacillus thuringiensis* and sample cards in open areas. Dashed lines represent the 95 percent confidence interval.

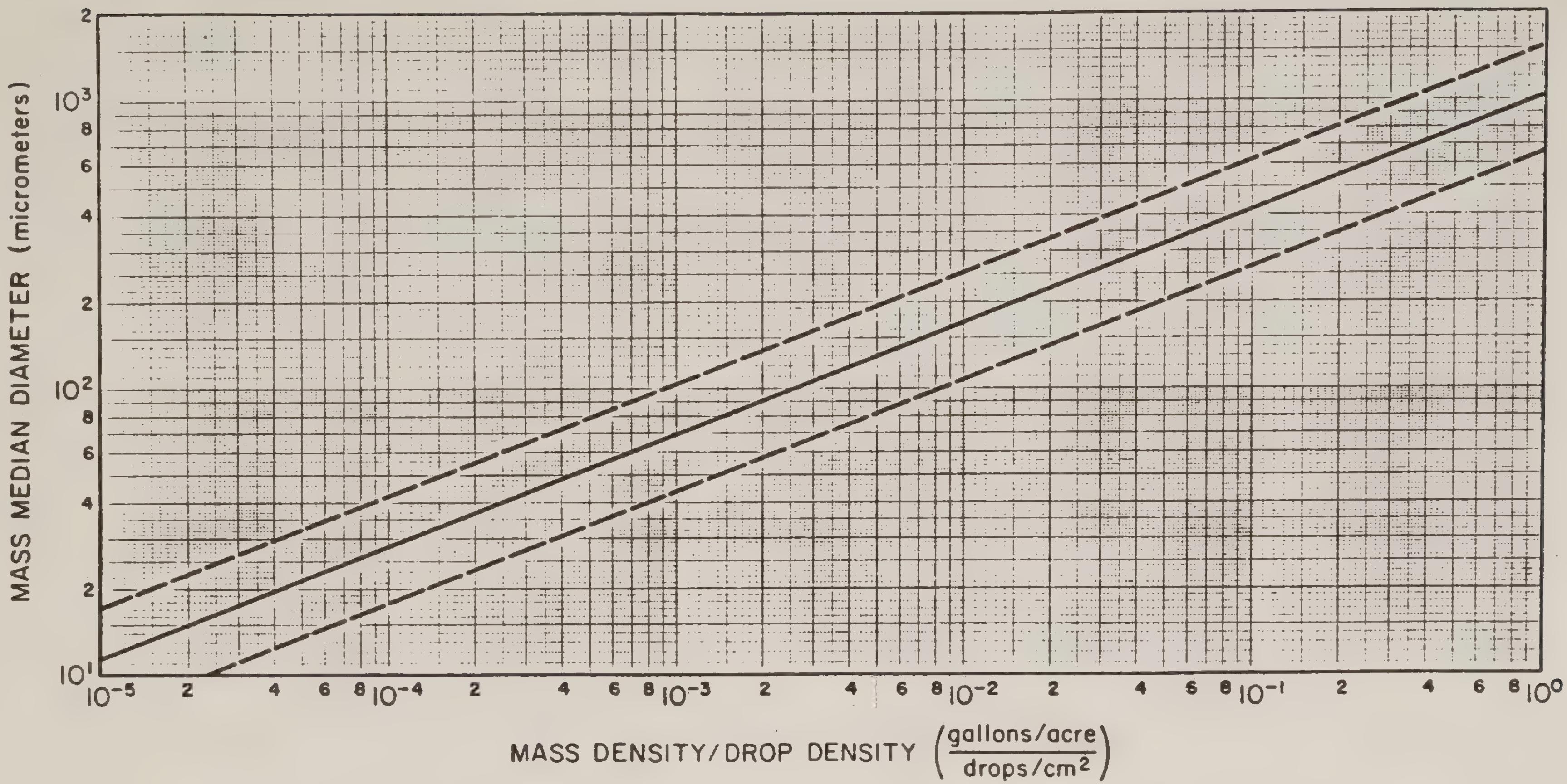
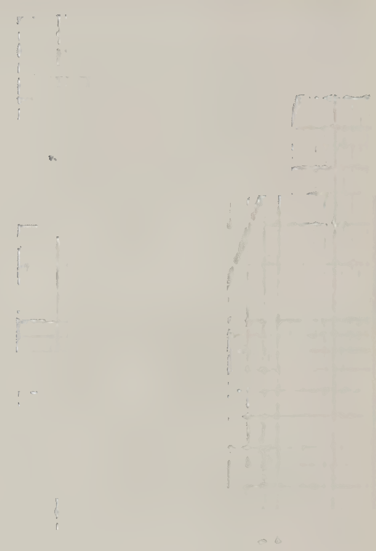


FIGURE A-6. Ratio of mass density and drop density versus mass median diameter for *Bacillus thuringiensis* and all sample cards. Dashed lines represent 95 percent confidence interval.



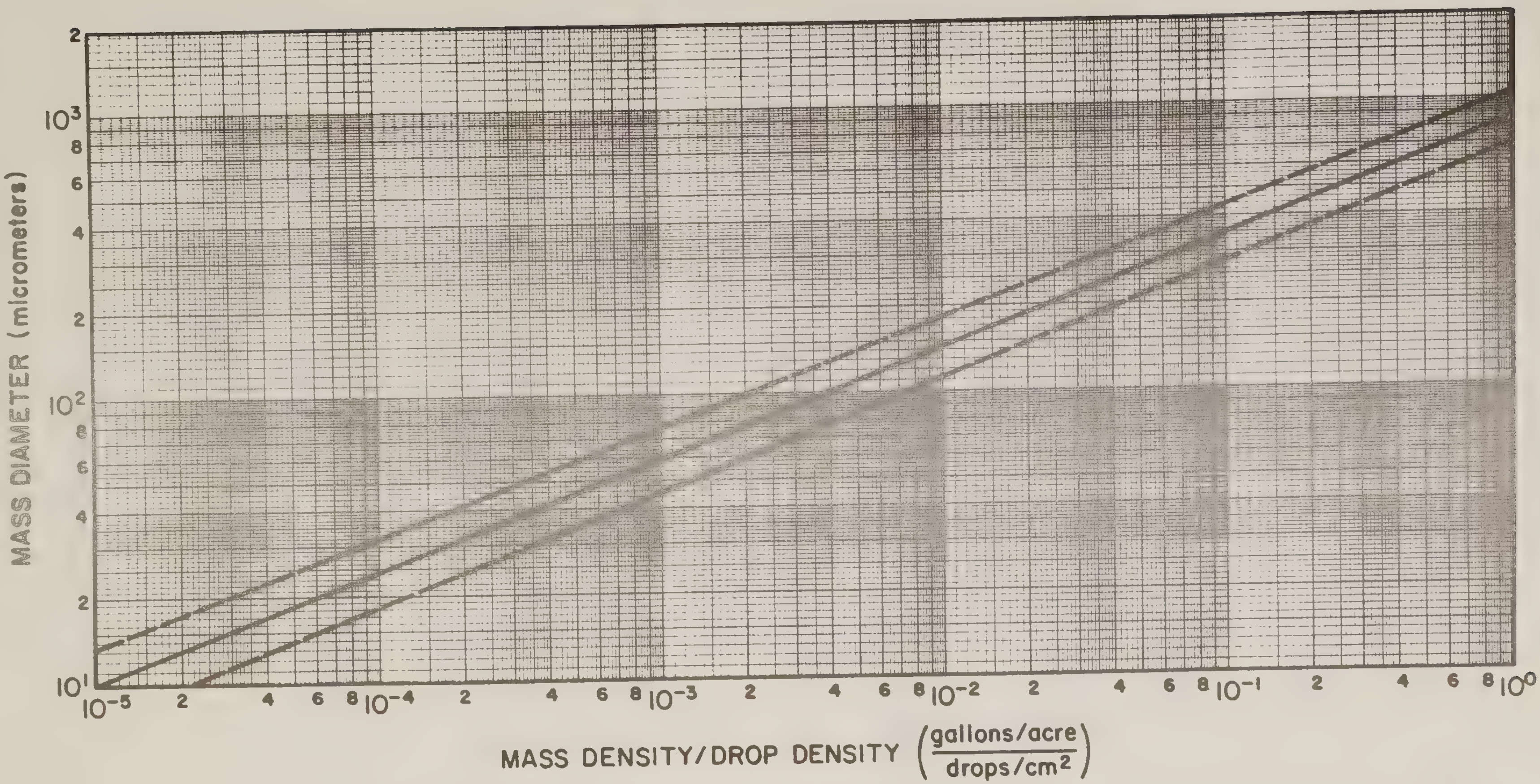


FIGURE A-7. Ratio of mass density and drop density versus mass median diameter for Orthene® and sample cards in open areas. Dashed lines represent the 95 percent confidence interval.

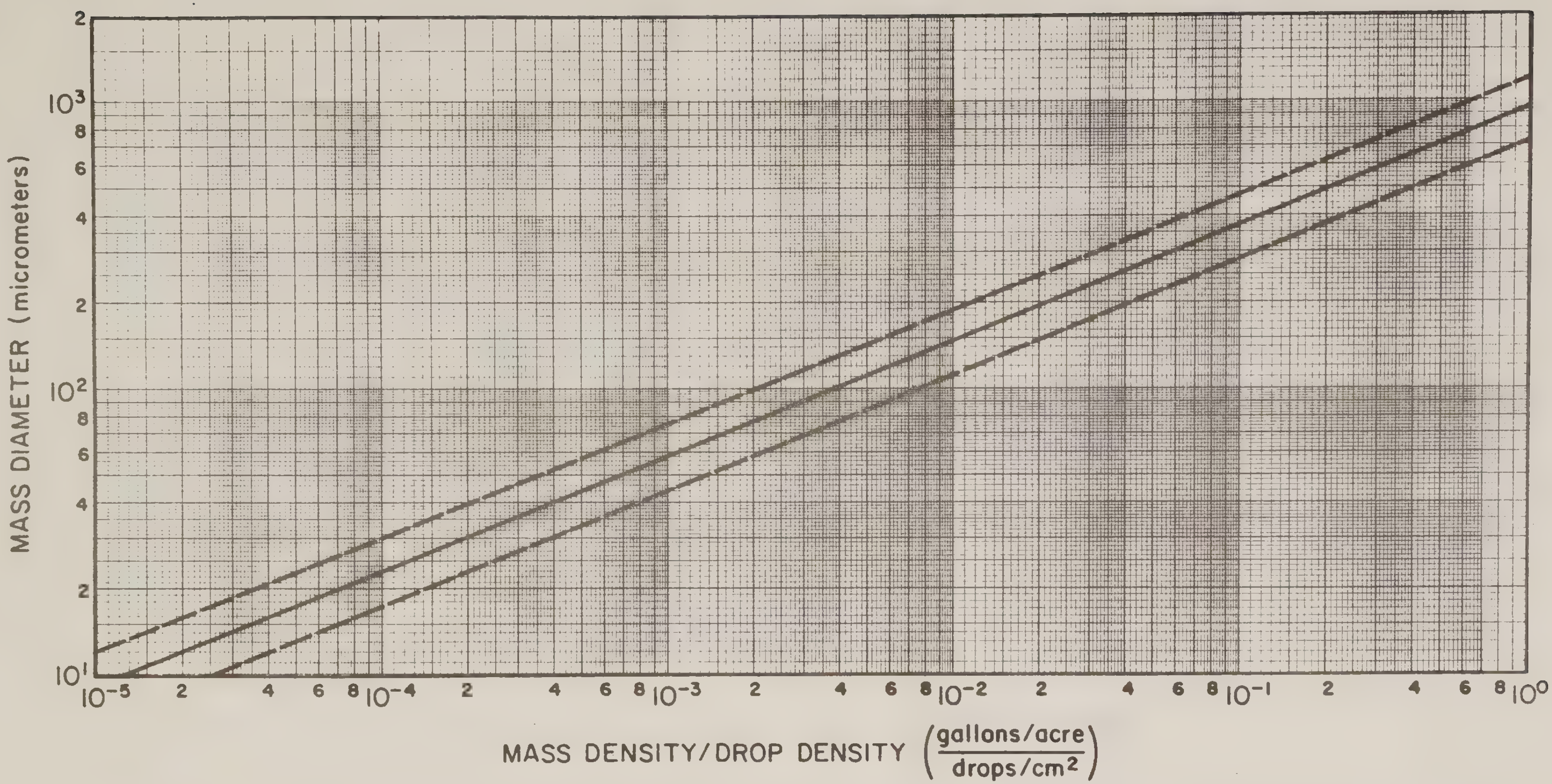


FIGURE A-8. Ratio of mass density and drop density versus mass median diameter for Orthene® and all sample cards. Dashed lines represent the 95 percent confidence interval.

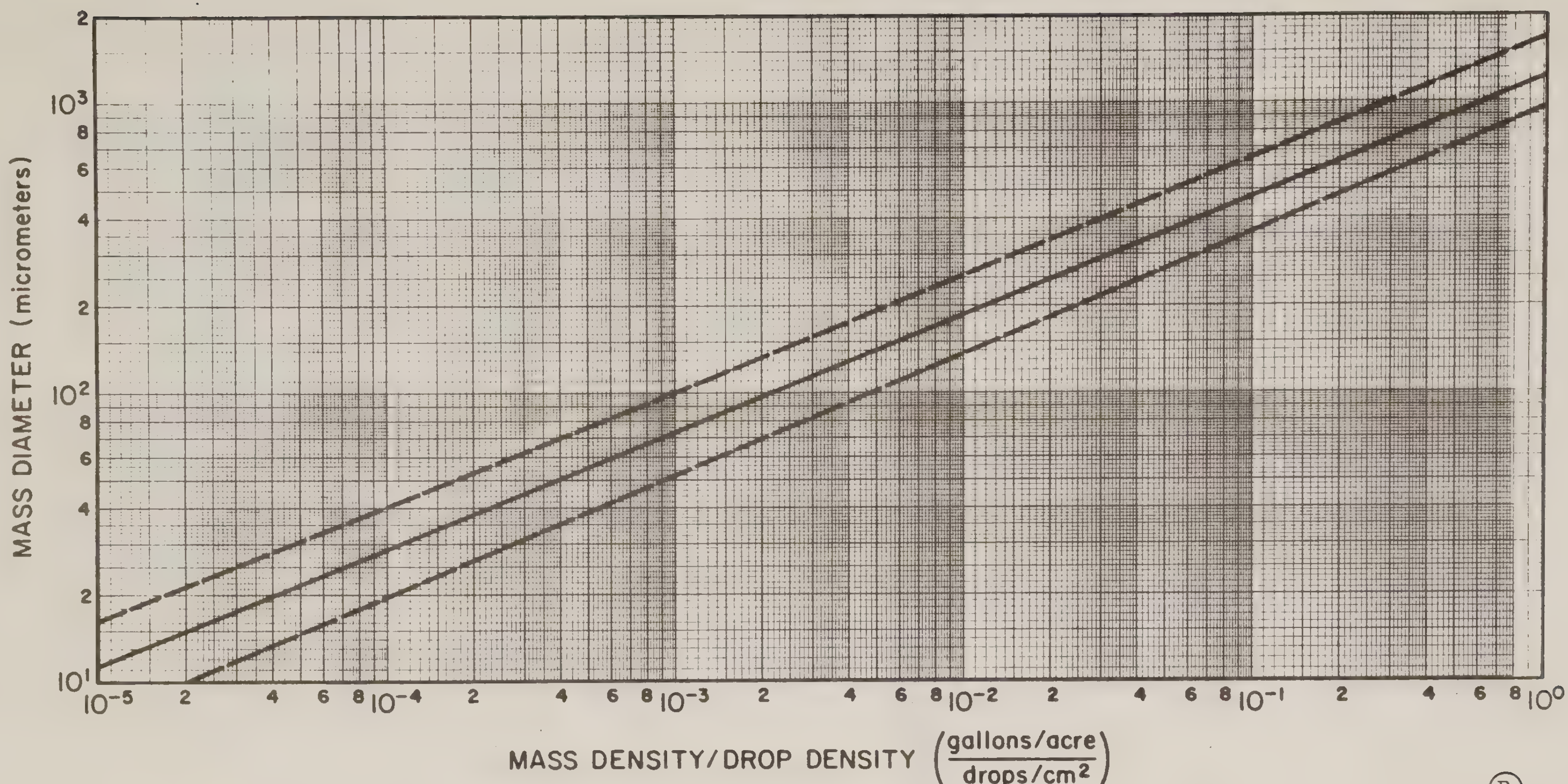


FIGURE A-9. Ratio of mass density and drop density versus mass median diameter for Zectran® and sample cards in the open areas. Dashed lines represent the 95 percent confidence interval.

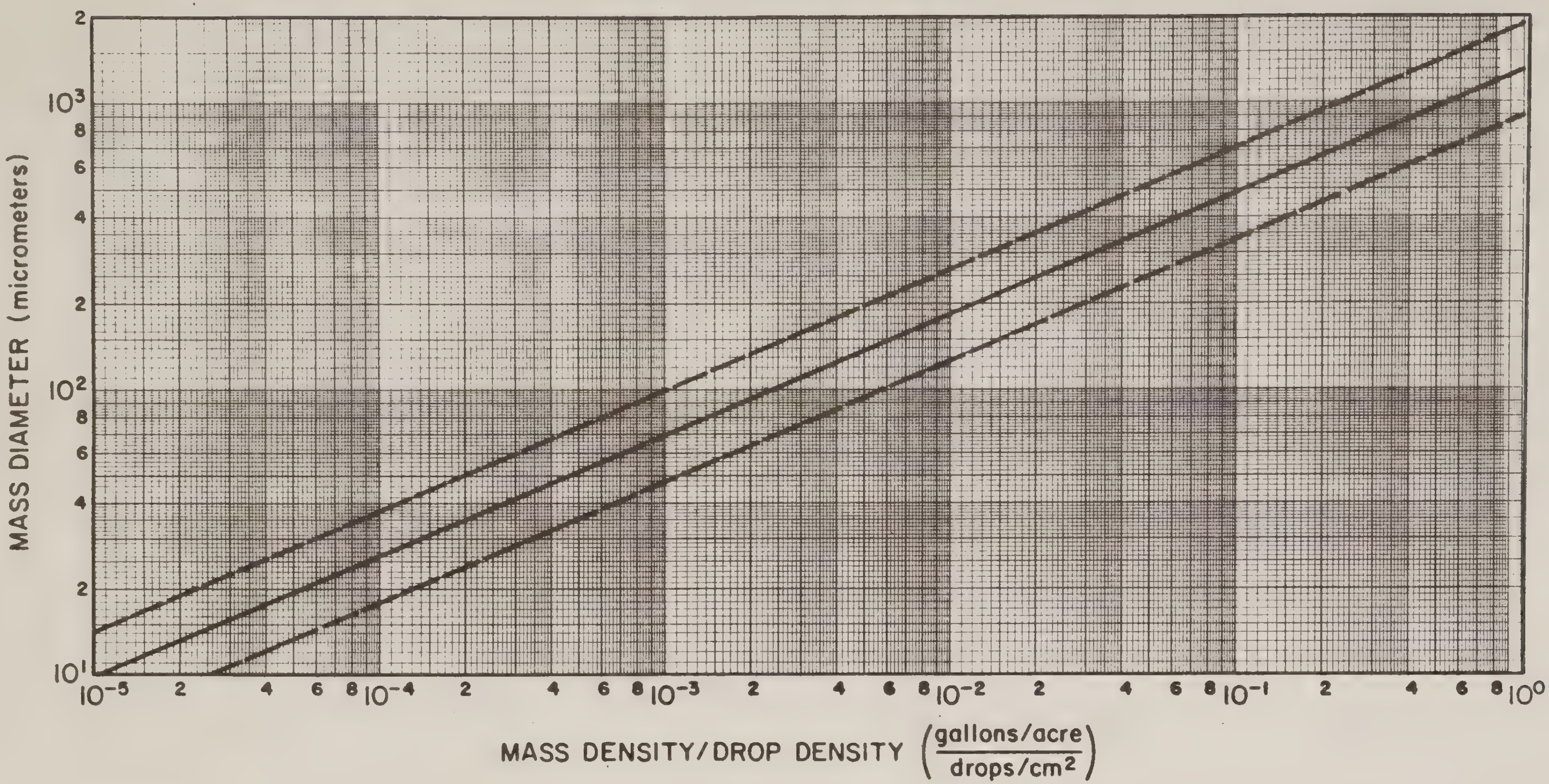


FIGURE A-10. Ratio of mass density and drop density versus mass median diameter for Zectran® and all sample cards. Dashed lines represent the 95 percent confidence interval.

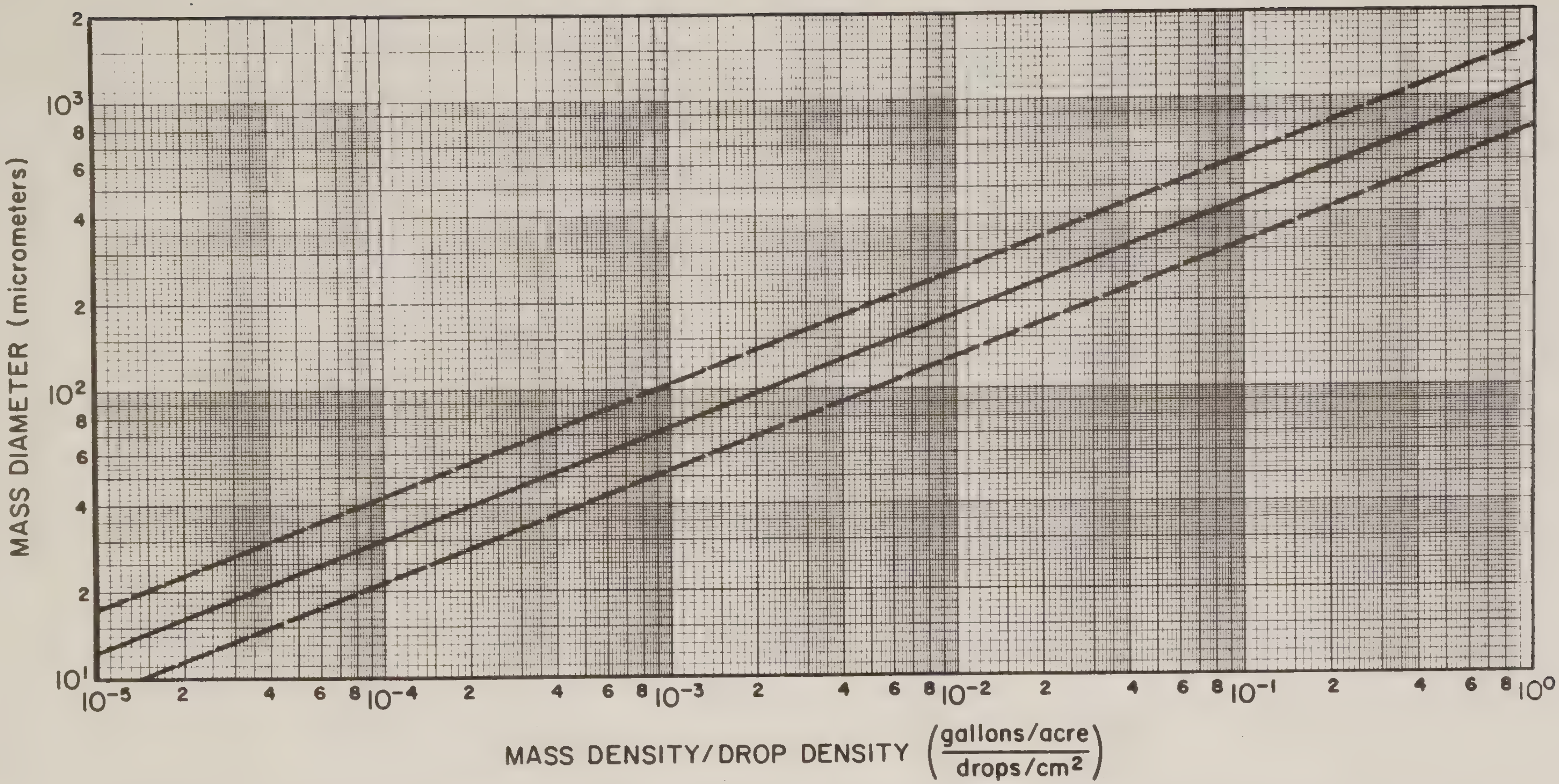


FIGURE A-11. Ratio of mass density and drop density versus mass median diameter for fuel oil and sample cards in open areas. Dashed lines represent the 95 percent confidence interval.

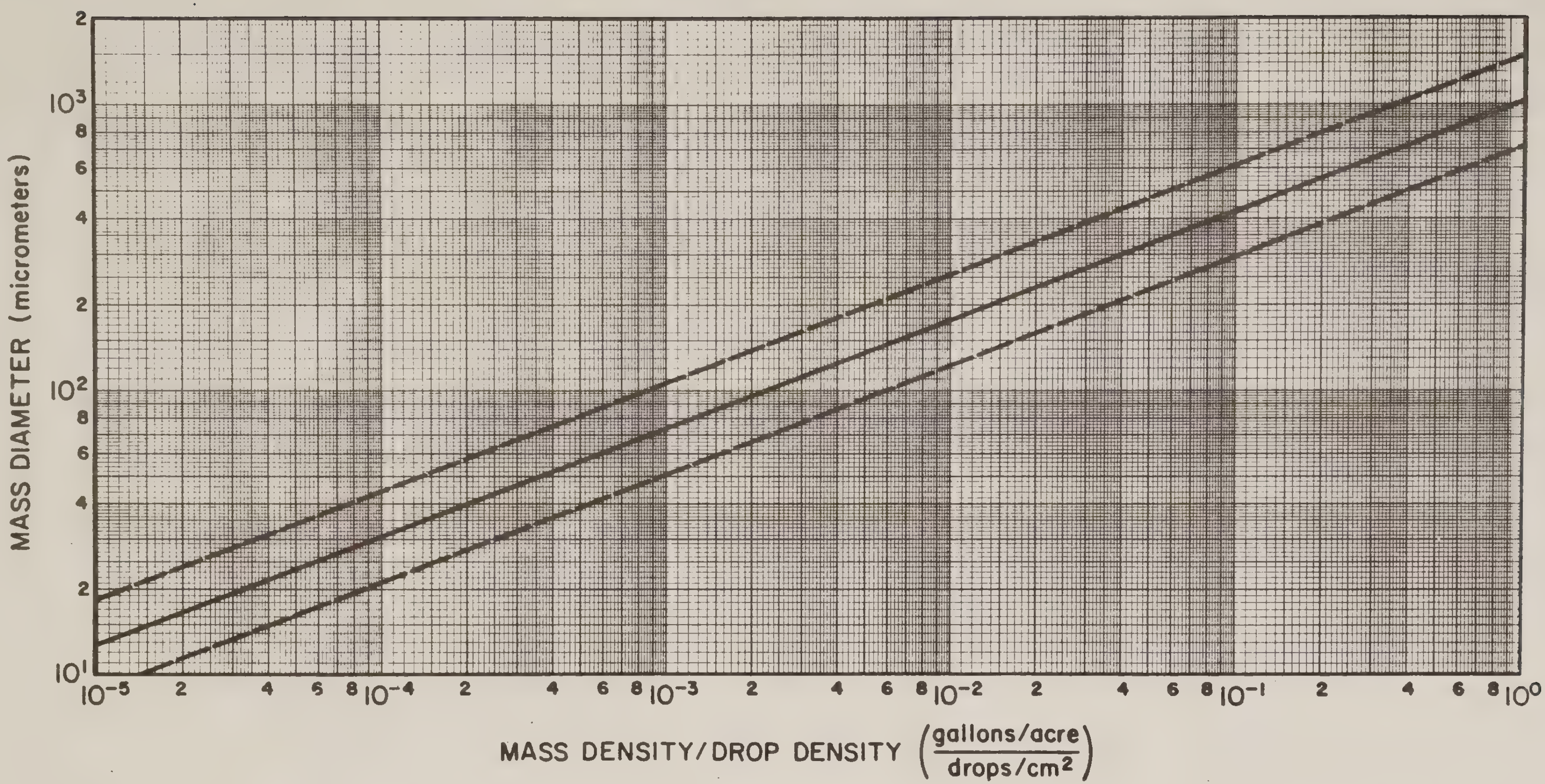


FIGURE A-12. Ratio of mass density and drop density versus mass median diameter for fuel oil and all sample cards. Dashed lines represent the 95 percent confidence interval.

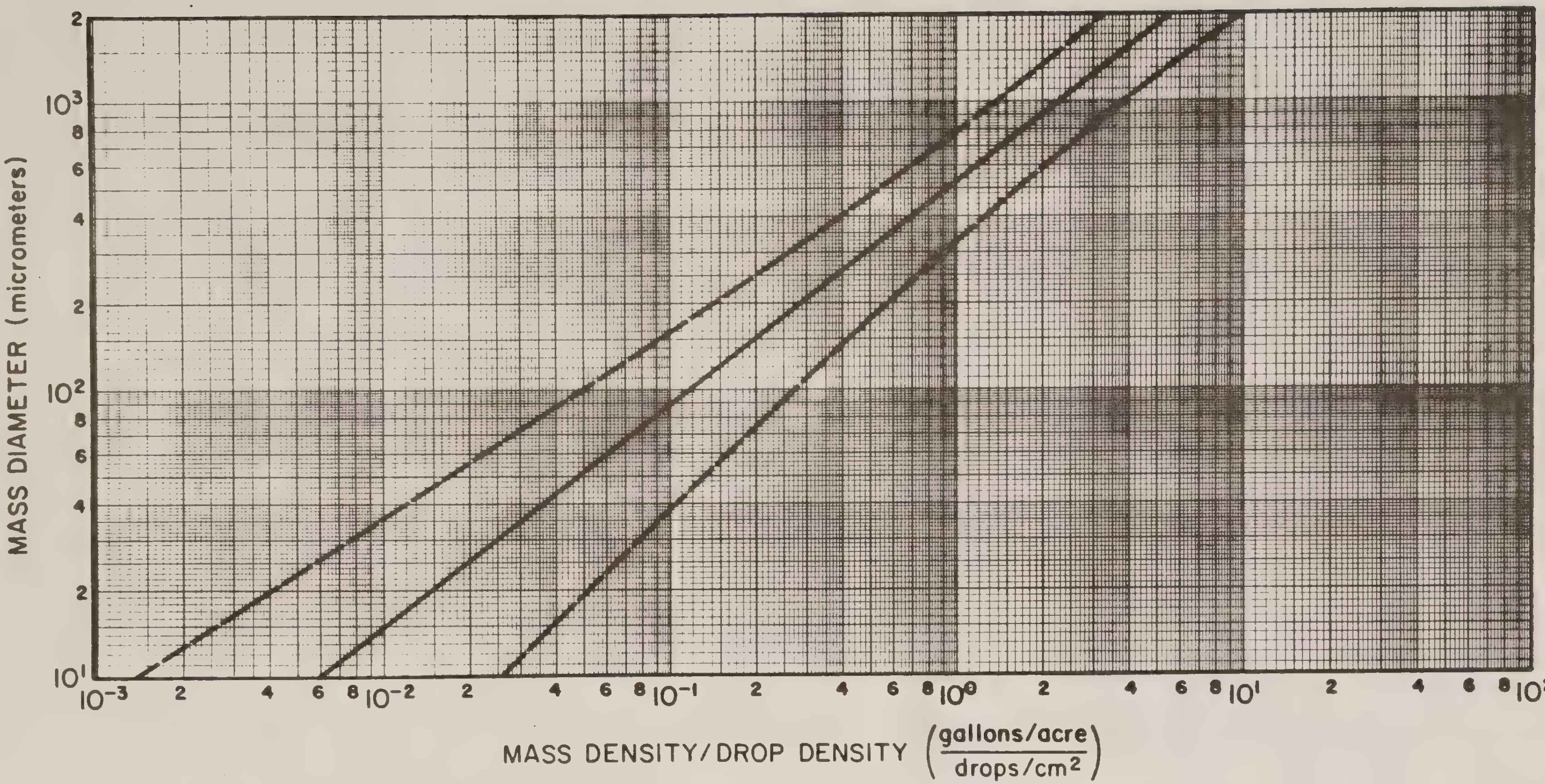


FIGURE A-13. Ratio of mass density and drop density versus mass median diameter for 2, 4-D and all sample cards. Dashed lines represent the 95 percent confidence interval.

APPENDIX B

This appendix contains nomographs for use in estimating the mass density on spray deposit cards using estimates of the drop density and mass median diameter for the card. Nomographs are given for estimating the mass densities of Dylox®, _Bacillus thuringiensis_, Orthene®, Sevin 4-Oil®, Zectran® and fuel oil on spray deposit cards in open areas and for all cards.

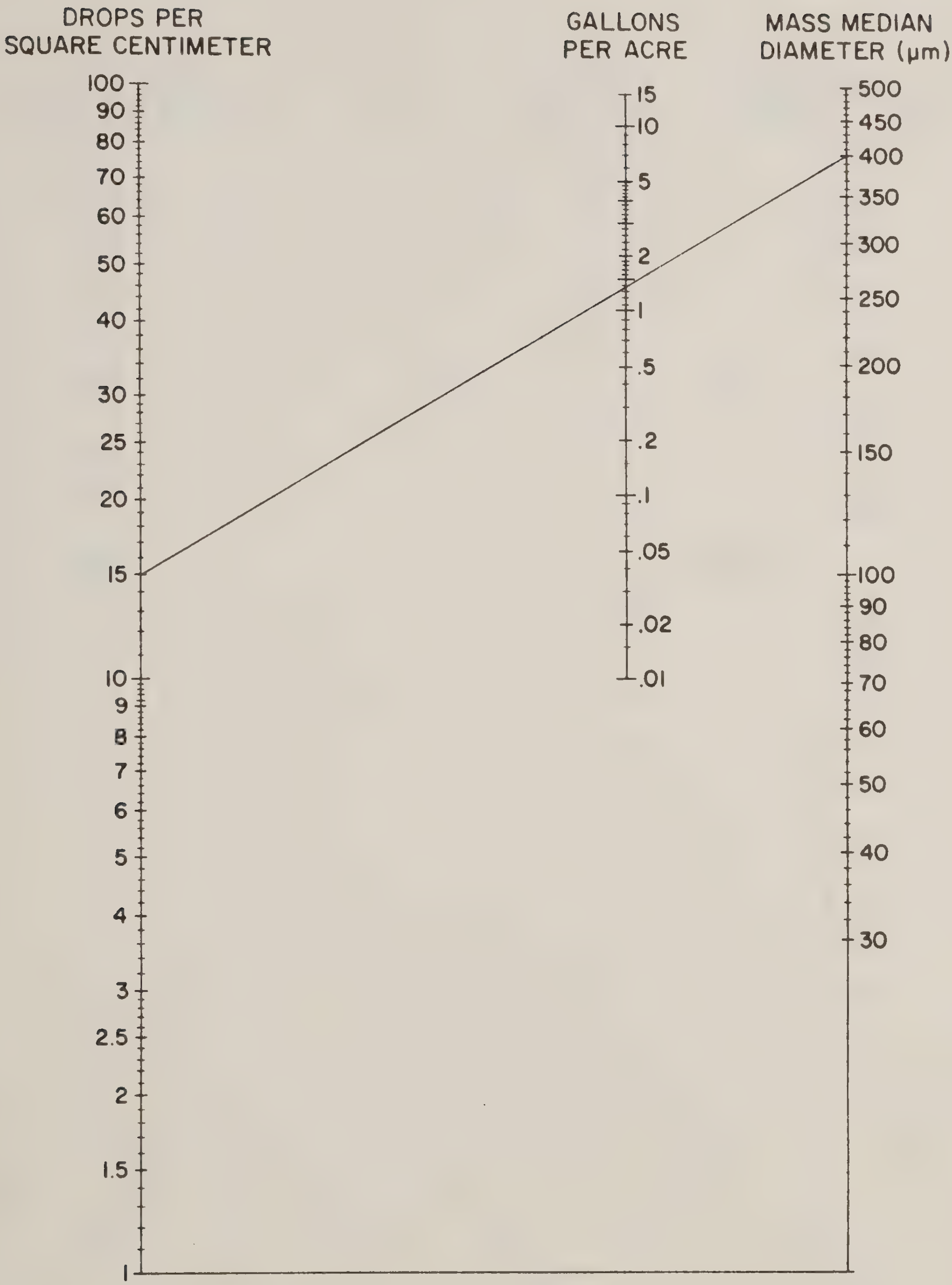


FIGURE B-1. Nomograph for field estimation of mass density (gallons/acre) of Dylox® from the mass median diameter and drop density (drops/square centimeter) on sample cards in the open.

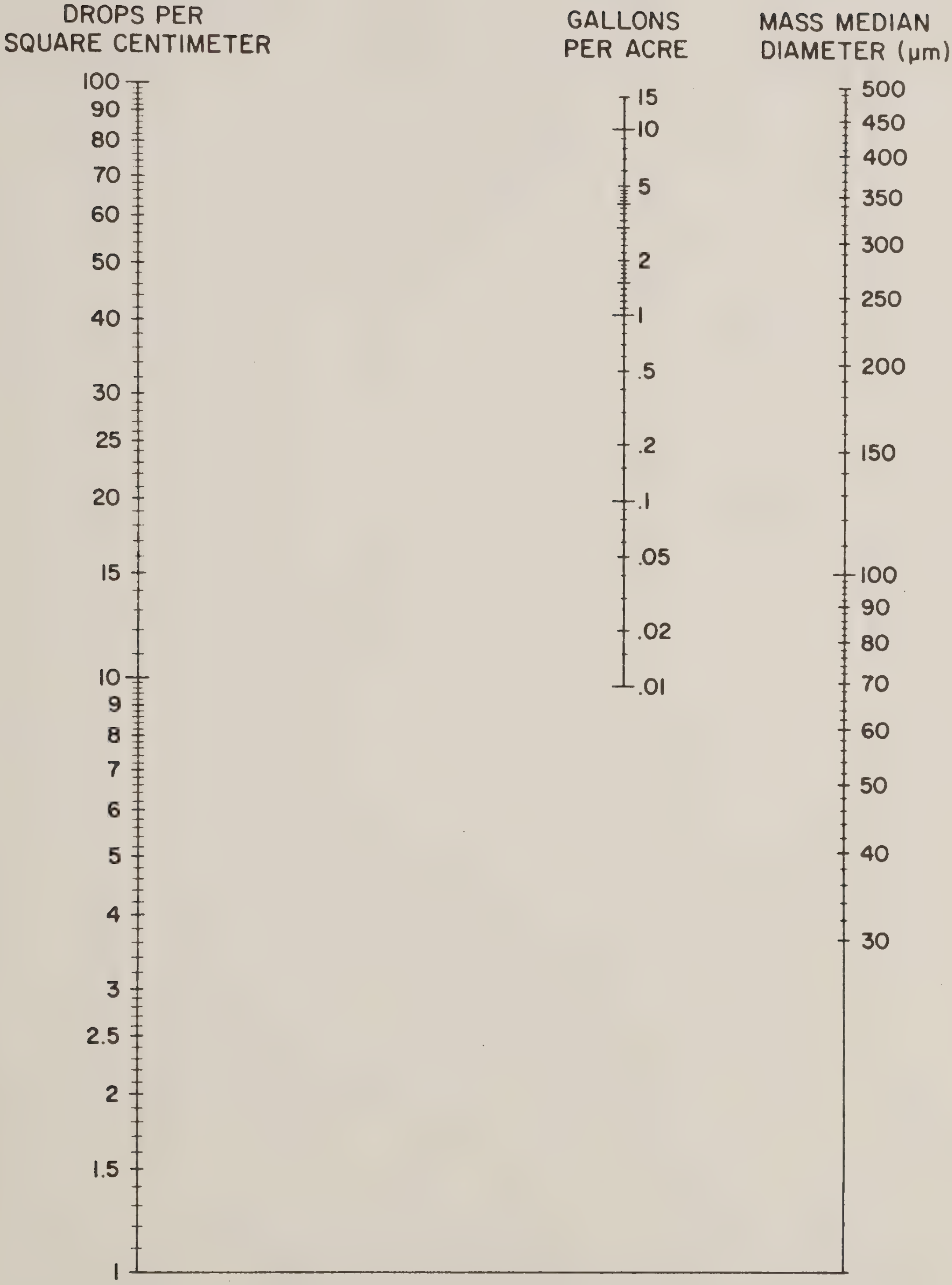


FIGURE B-2. Nomograph for field estimation of mass density (gallons/acre) of Dylox® from the mass median diameter and drop density (drops/square centimeter) on all sample cards.

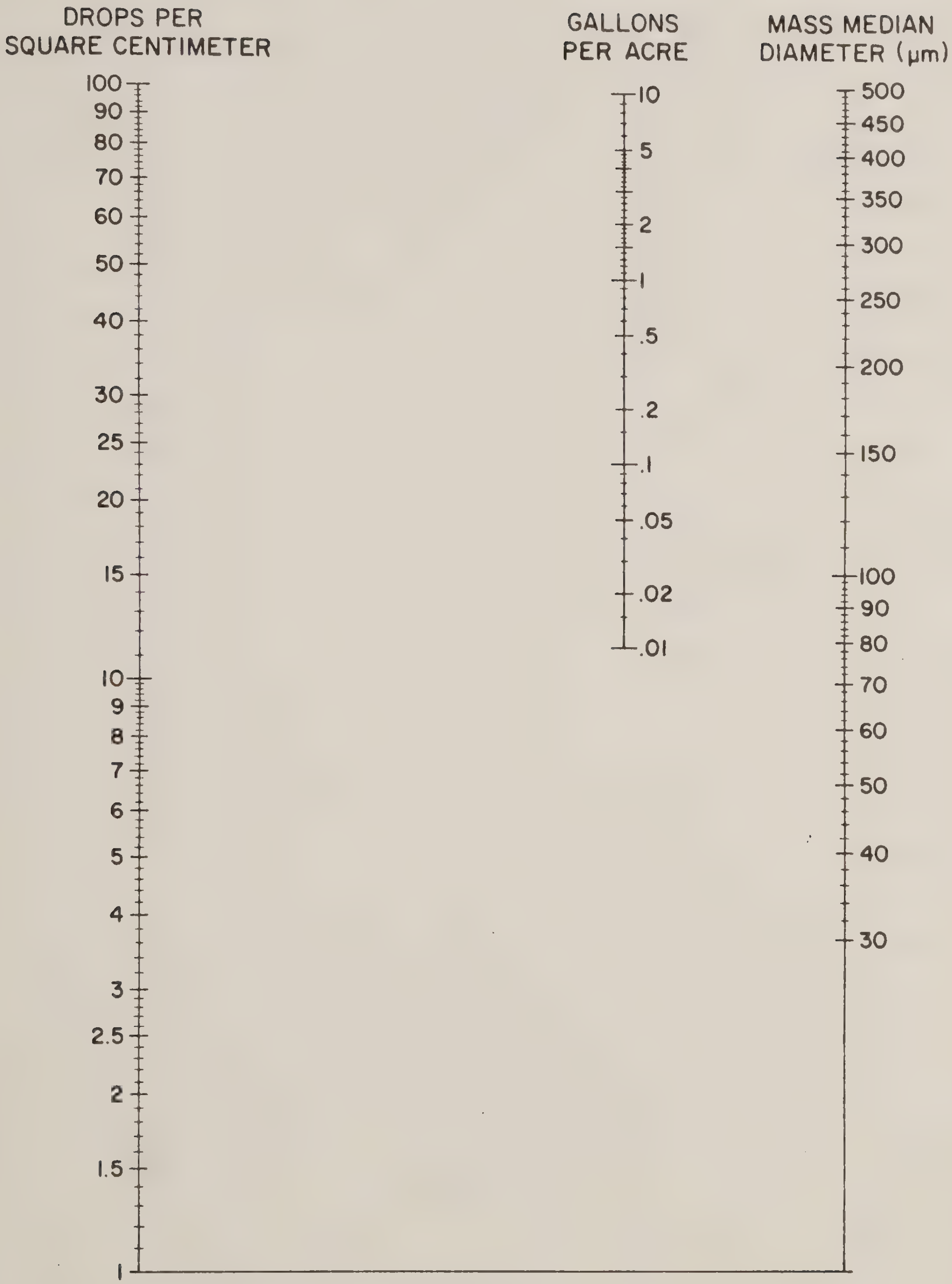


FIGURE B-3. Nomograph for field estimation of mass density (gallons/acre) of Sevin 4-Oil® from the mass median diameter and drop density (drops/square) centimeter) on sample cards in the open.

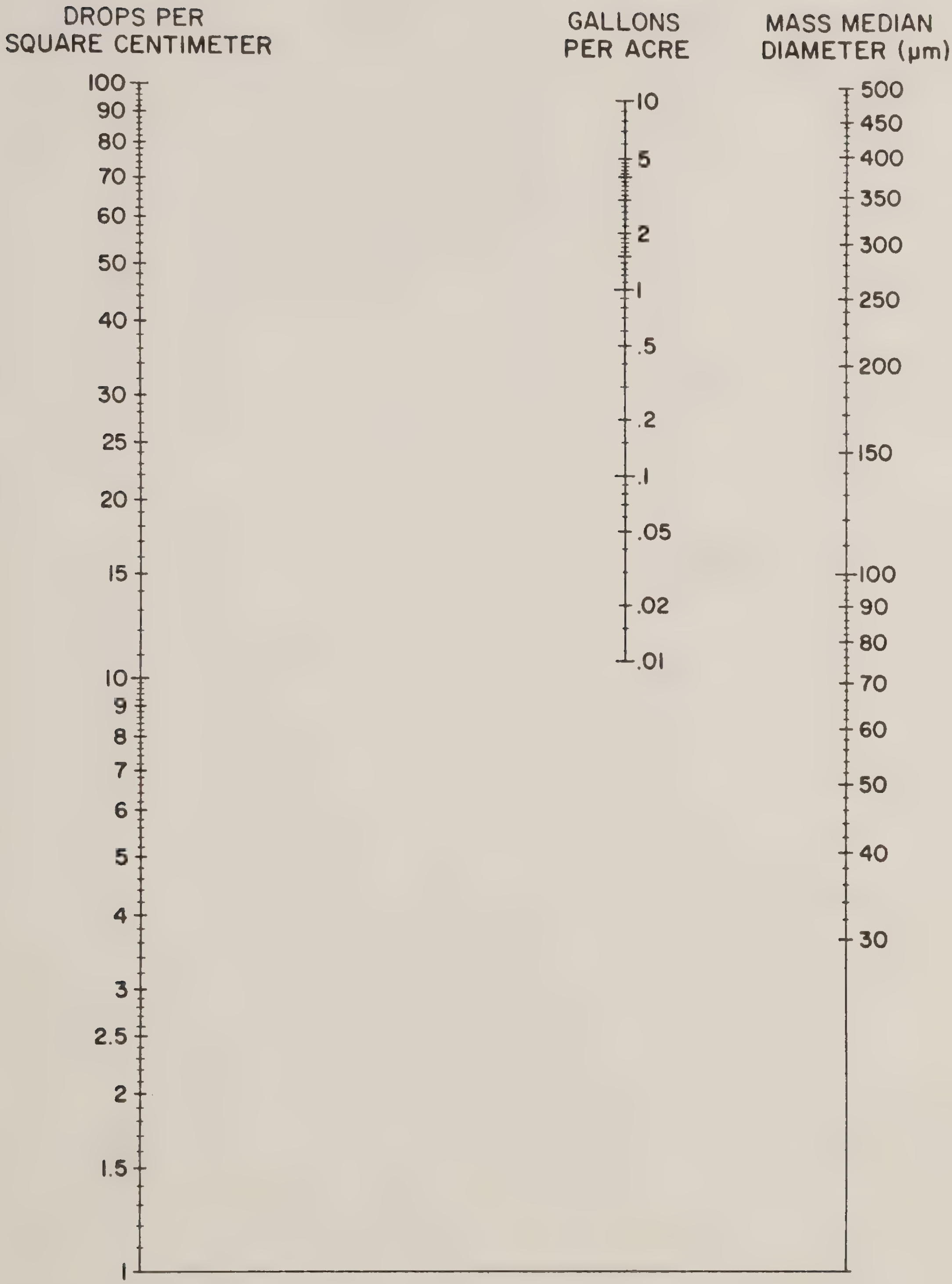


FIGURE B-4. Nomograph for field estimation of mass density (gallons/acre) of Sevin 4-Oil® from the mass median diameter and drop density (drops/square centimeter) on all sample cards.

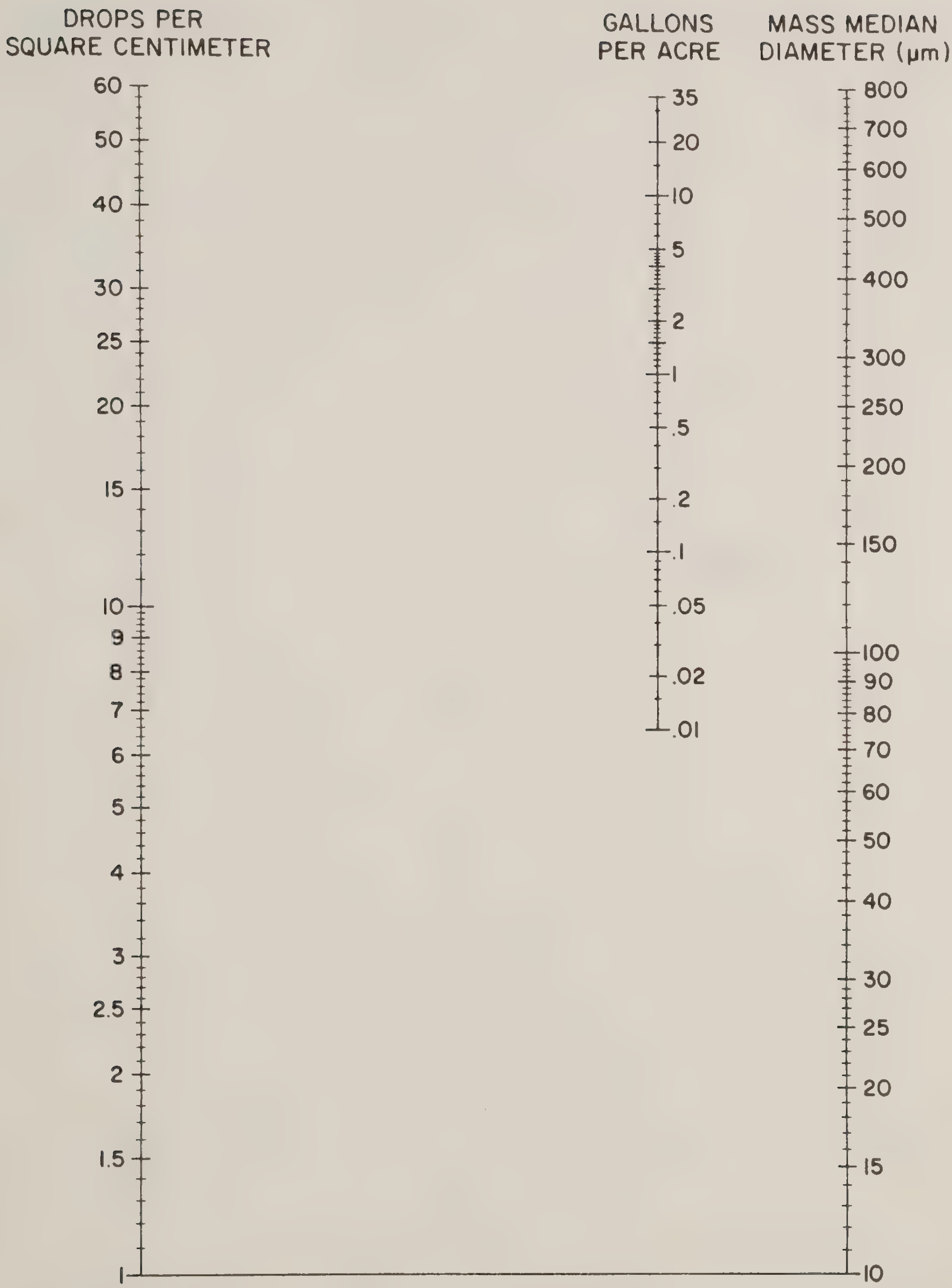


FIGURE B-5. Nomograph for field estimation of mass density (gallons/acre) of Bacillus thuringiensis from the mass median diameter and drop density (drops/square centimeter) on sample cards in the open.

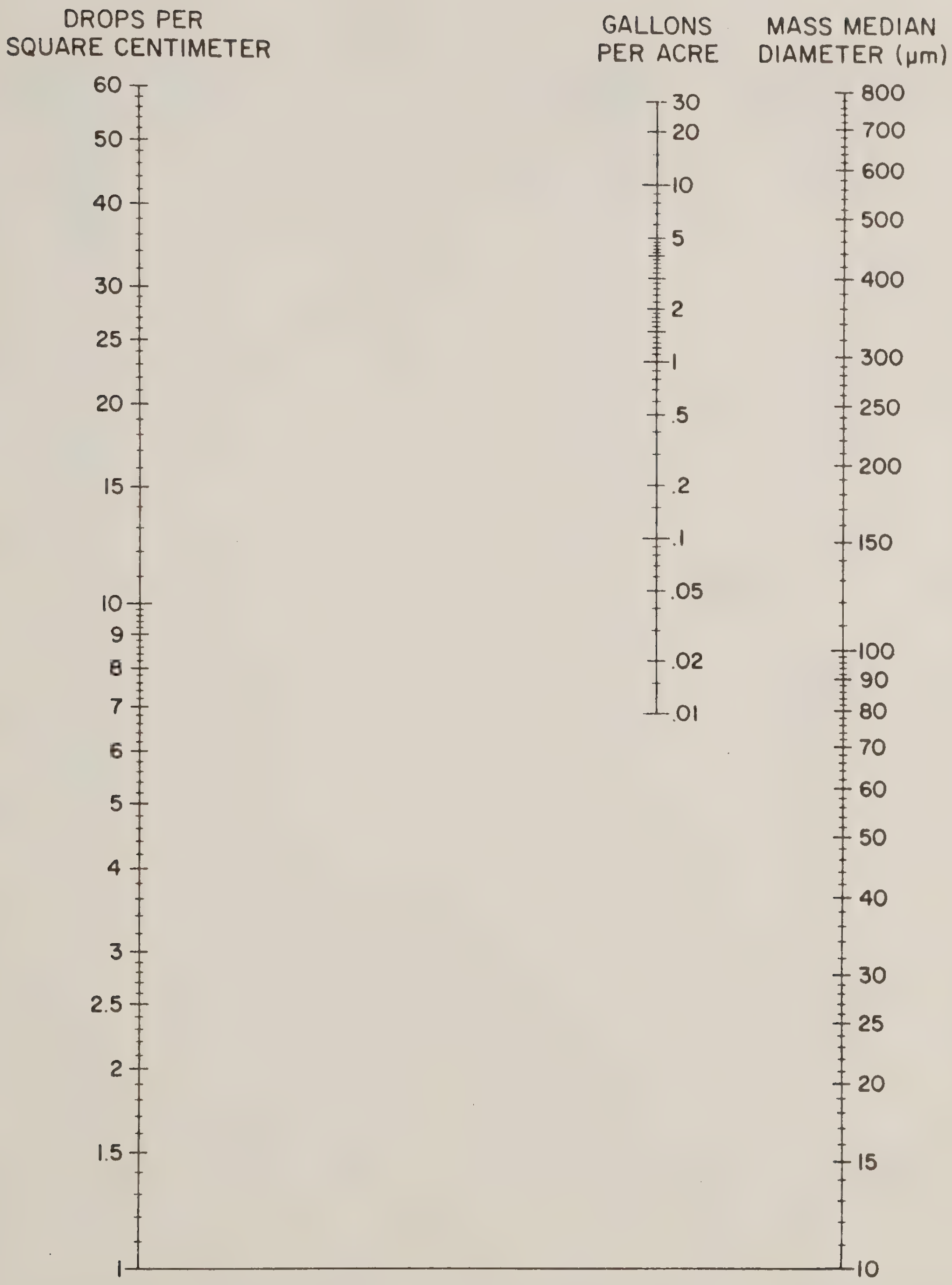


FIGURE B-6. Nomograph for field estimation of mass density (gallons/acre) of Bacillus thuringiensis from the mass median diameter and drop density (drops/square centimeter) on all sample cards.

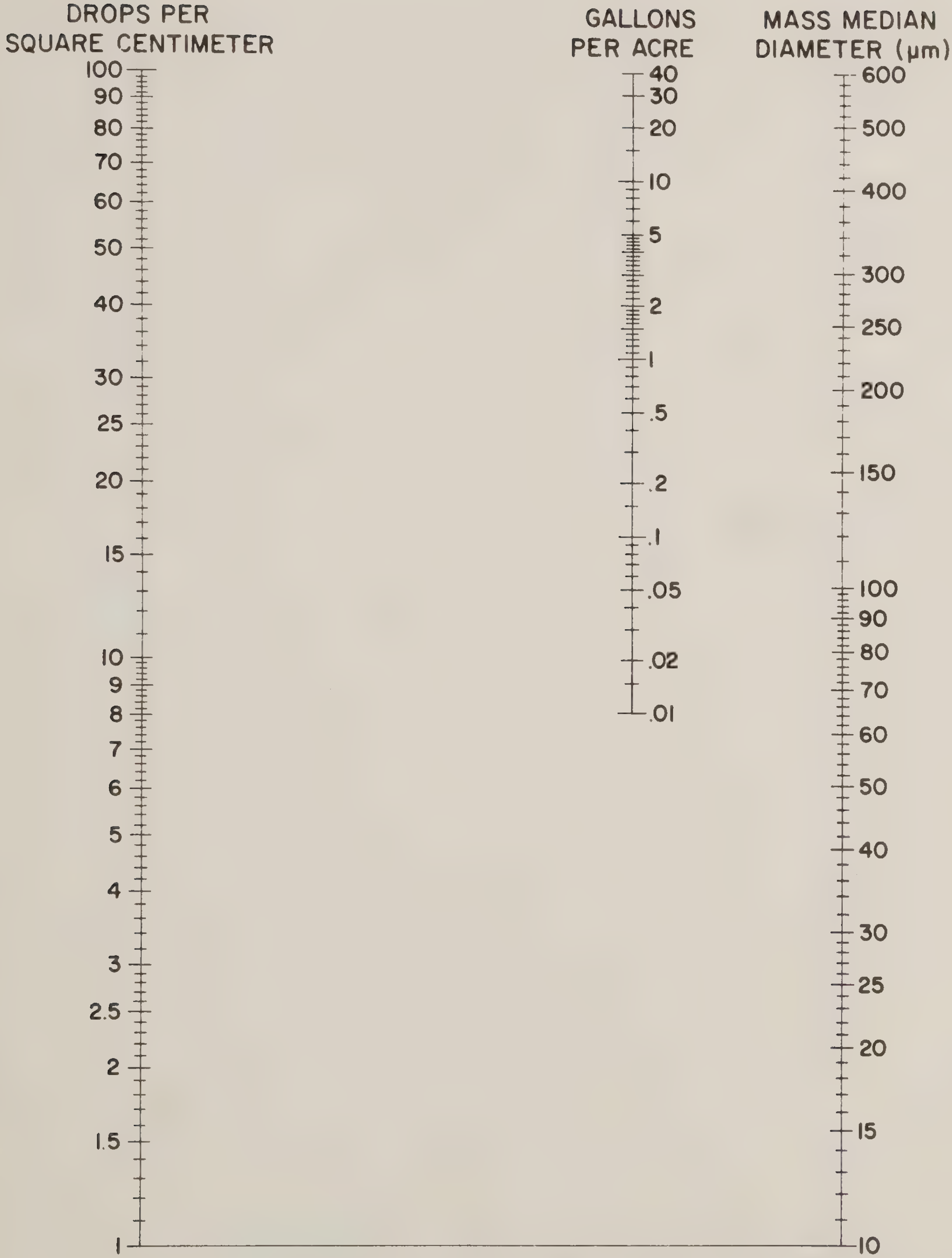


FIGURE B-7. Nomaograph for field estimation of mass density (gallons/acre) of Orthene® from the mass median diameter and drop density (drop/square centimeter) on sample cards in the open.

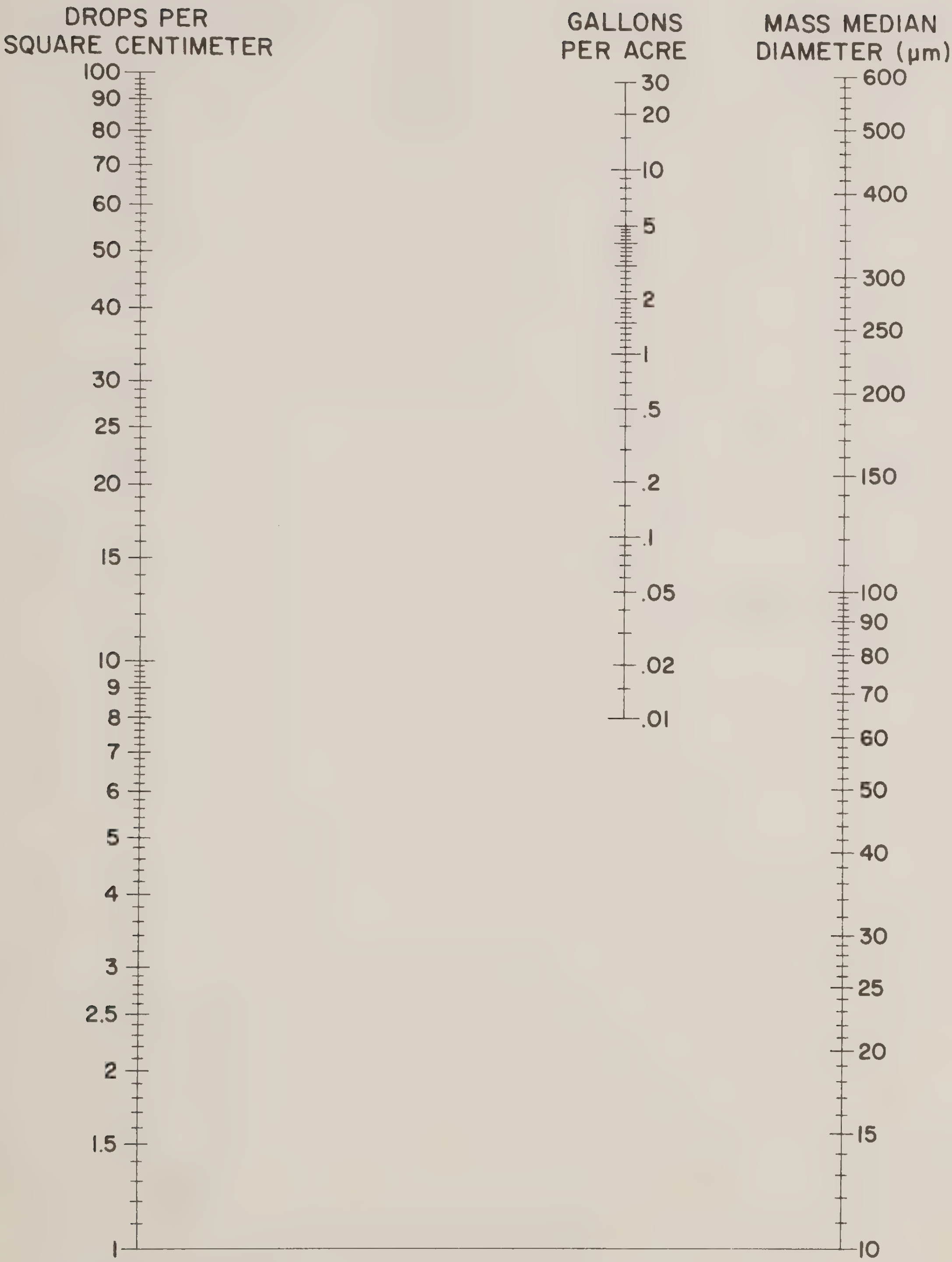


FIGURE B-8. Nomograph for field estimation of mass density (gallons/acre) of Orthene® from the mass median diameter and drop density (drops/square centimeter) on all sample cards.

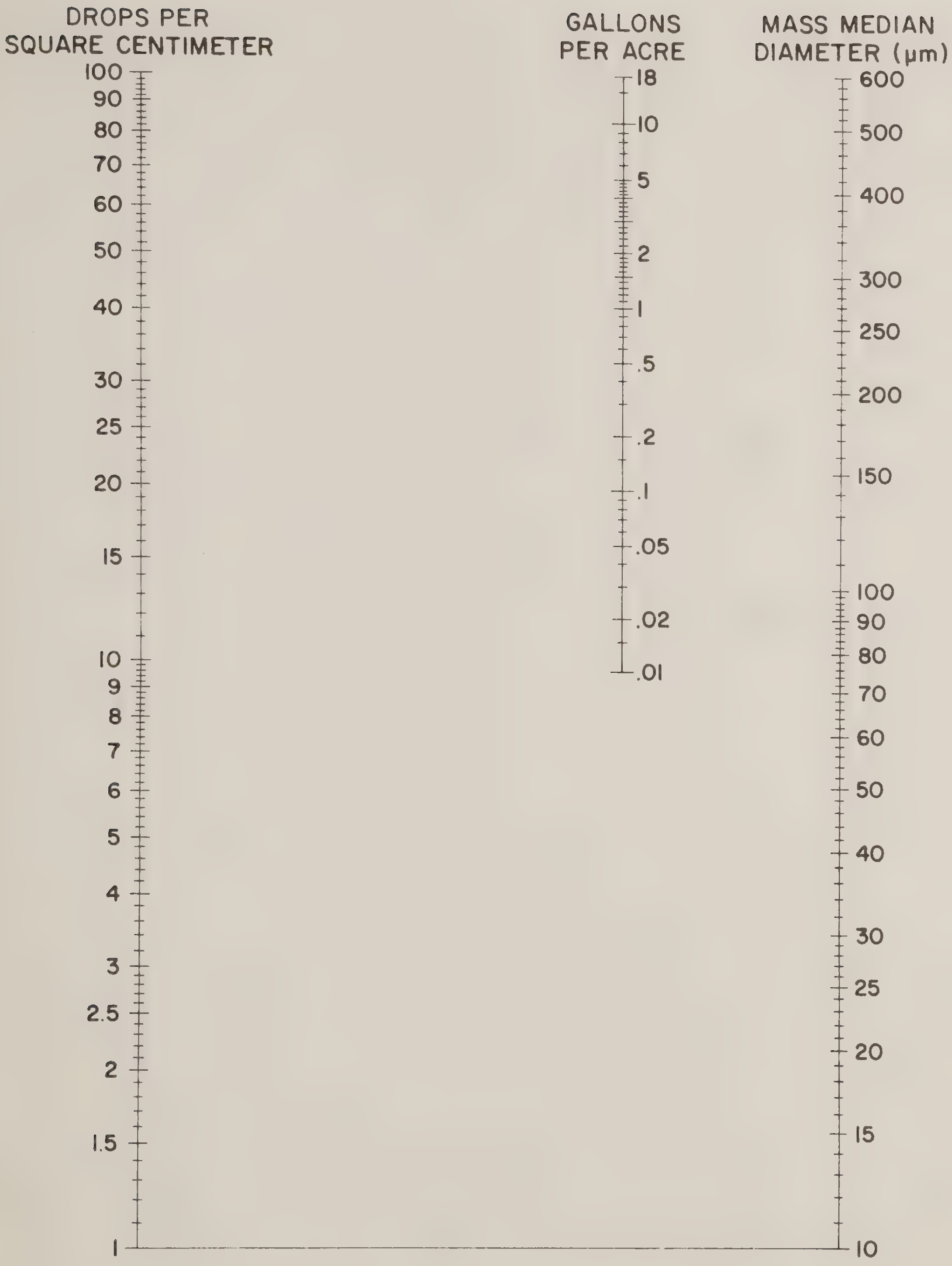


FIGURE B-9. Nomograph for field estimation of mass density (gallons/acre) of Zectran® from the mass median diameter and drop density (drops/square centimeter) on sample cards in the open.

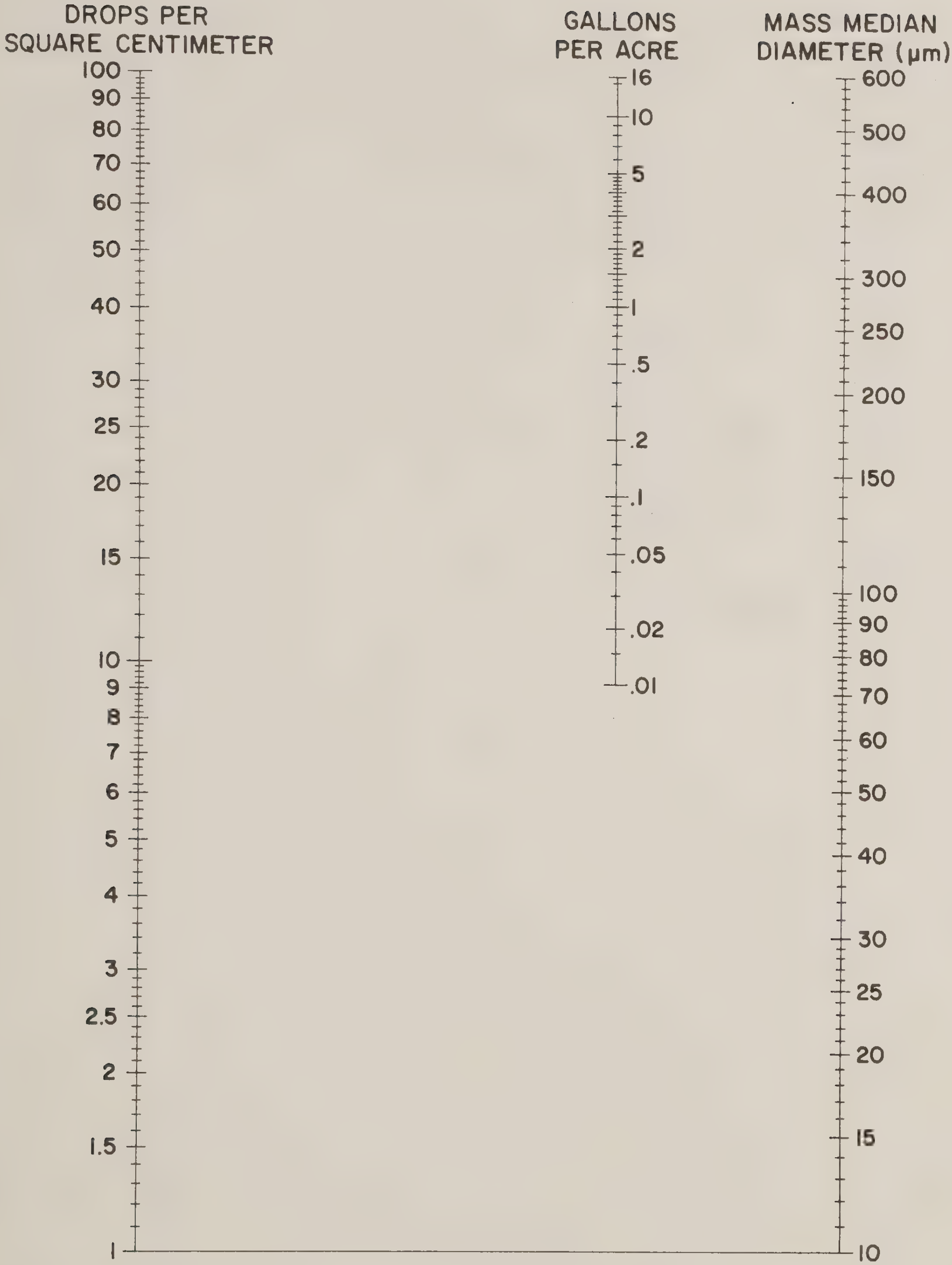


FIGURE B-10. Nomograph for field estimation of mass density (gallons/acre) of Zectran® from the mass median diameter and drop density (drops/square centimeter) on all sample cards.

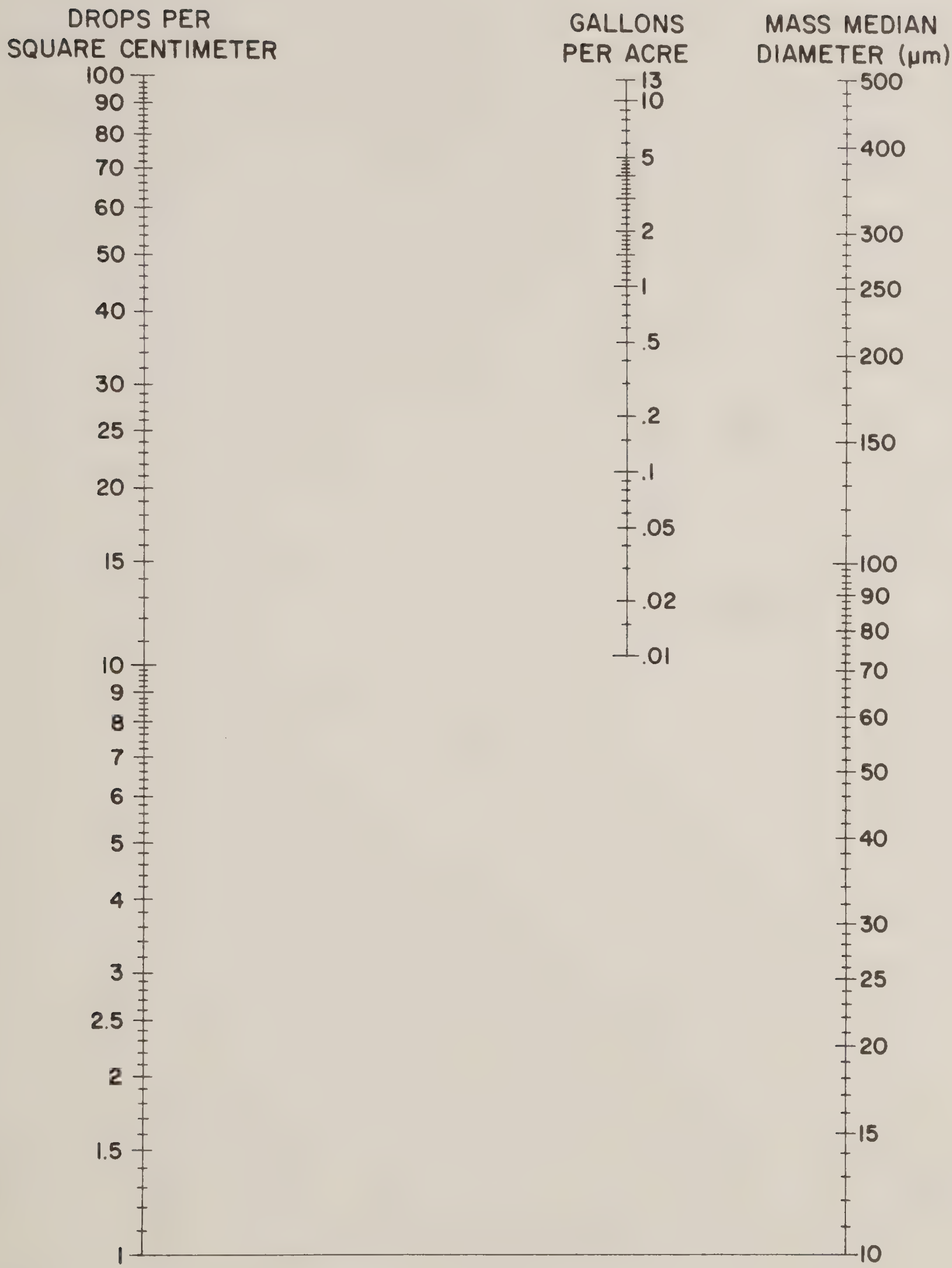


FIGURE B-11. Nomograph for field estimation of mass density (gallons/acre) of fuel oil from the mass median diameter and drop density (drops/square centimeter) on sample cards in the open.

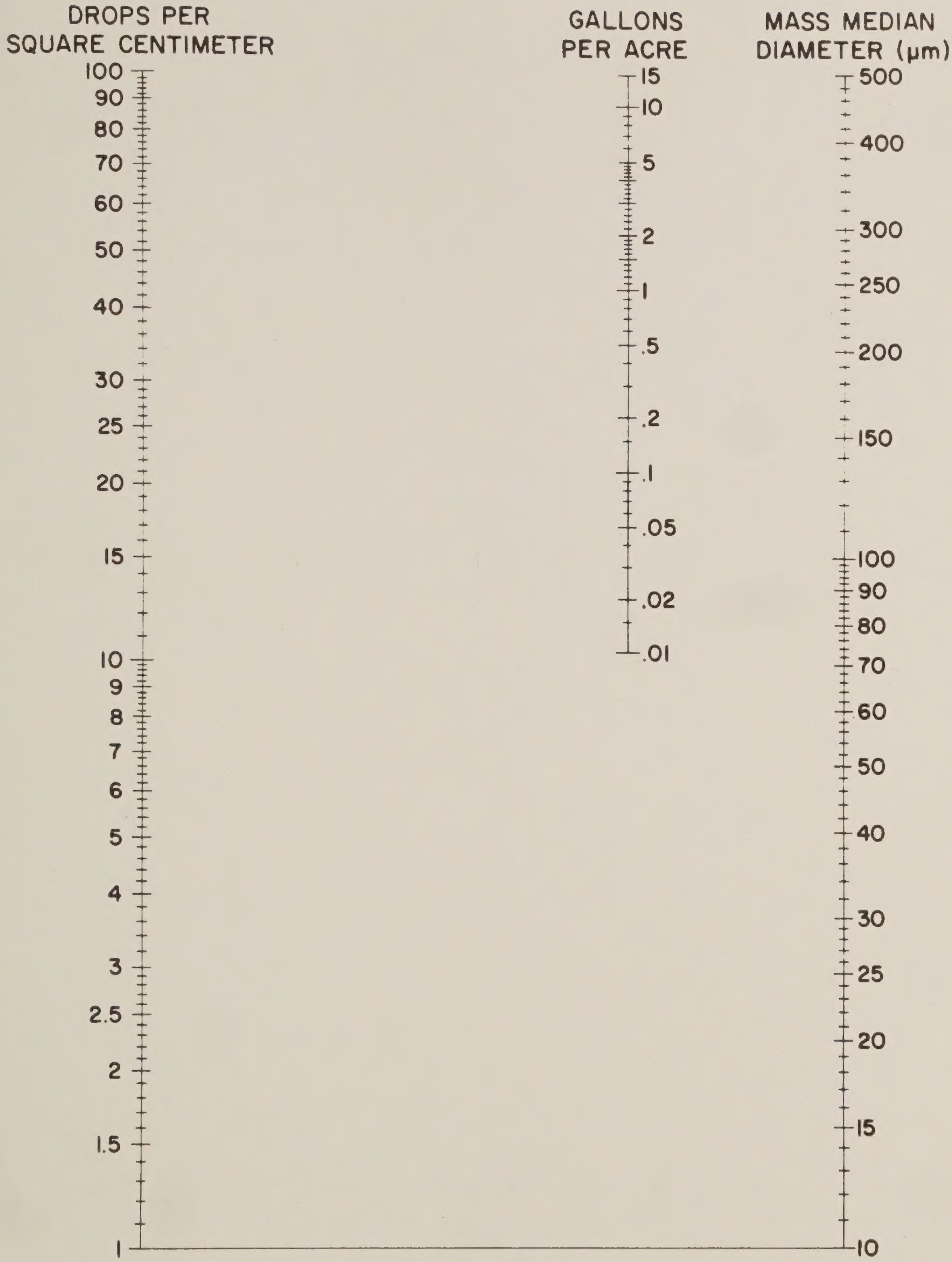


FIGURE B-12. Nomograph for field estimation of mass density (gallons/acre) of fuel oil from the mass median diameter and drop density (drops/square centimeter) on all sample cards.